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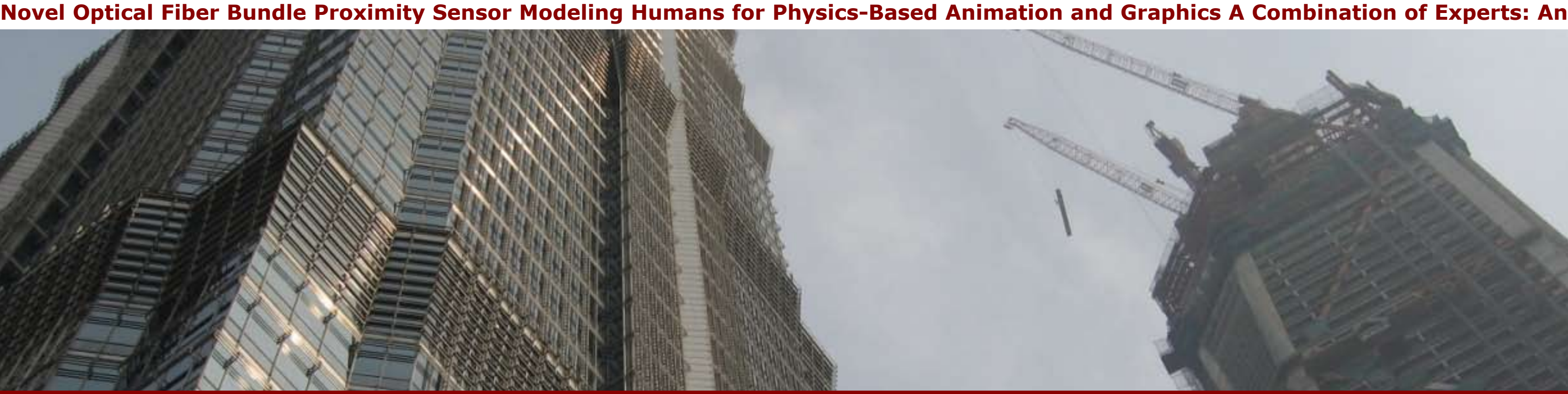
History of Stanford Masters EE Program What does Gender Inequality Really Mean? Waterfall-Generated Earth Vibrations The Return of the Dragon: Scientific Promise of China All the World's An Interface The Integrated Circuits Laboratory A Taste of Bioengineering A Novel Optical Fiber Bundle Proximity Sensor Modeling Humans for Physics-Based Animation and Graphics A Combination of Experts: An



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editors' notes

Since its inception in 2003, the Stanford Electrical Engineering and Computer Science Research Journal (ECJ) has focused on the promotion of research in the Electrical Engineering and Computer Science disciplines. The last two issues of ECJ have featured interesting and cutting-edge academic papers from the Stanford student community, but there is more to research than just science. Scientific research is not just about theories, equations, experiments, and proofs. Behind every scientific discovery or success, there is a person, a story, a community. In this year's issue, we have expanded ECJ to strive to capture this human element of engineering.

In the spirit of giving a voice to the student engineering community at Stanford, the community pieces represent the opinions, passions, advices, and experiences of your fellow students. These pieces convey insights and stories from a quarter abroad, an investigation into Stanford Engineering's history, or the retrospectives of graduating seniors. Regardless of whether their views represent the reader's Stanford experience, these writers are a part of our program and we strongly believe that their thoughts offer great insights into the Stanford EECS community.

Staying true to ECJ's original mission of promoting research, we have expanded the journal to feature class projects and REU/CURIS reports in addition to independent submissions as in the past. These REU/CURIS projects are the product of an entire summer or longer of hard work by fellow students who have worked closely with a Stanford faculty member. The recognized REU/CURIS projects have been carefully selected by ECJ editors with faculty input, and represent some of the best student work from the summer of 2007. For the upcoming issue of ECJ, we invite all summer 2008 REU and CURIS students to submit reports of their work for publication.

Finally, the ECJ team would like to express its warmest appreciation to our sponsors – the Stanford Electrical Engineering Department and IEEE Santa Clara Valley Council. Their generous support has made this issue of ECJ possible.

We hope that you find the articles in this journal interesting, and more importantly, relevant. We urge the reader to not only take part in research, but to also join in the discussion within our community.

Best,
Ian Wong
Gary Chang

staff

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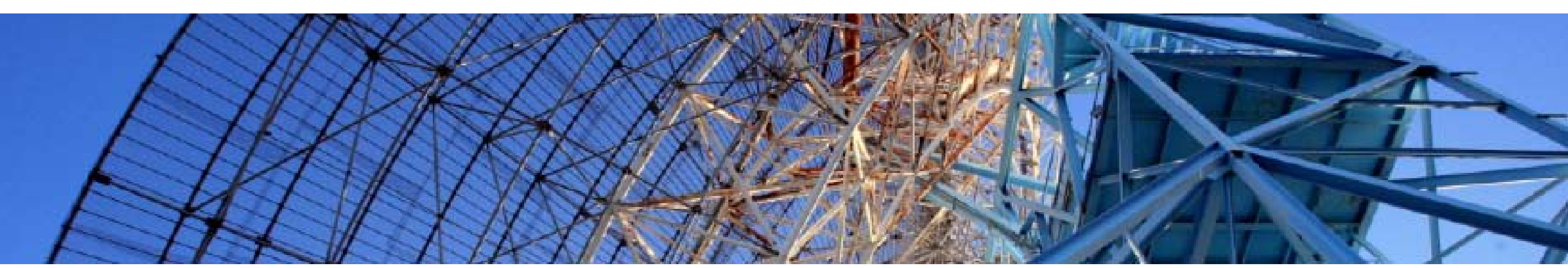

Cover Design by Gary Chang

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community

What Does Gender Equality Really Mean?

A Glimpse into the State of Women Engineers at Stanford

By Erin Hsu

15%

85%

The status of females in engineering is an issue that in recent years has been widely researched and discussed, almost to the point that it no longer draws much attention from males and females alike. The solutions that address the dearth of women in engineering are often too general or long-term to consider, and the breadth of the problem makes it hard to tackle. Focusing on the situation at Stanford, and particularly in the Electrical Engineering department, is much more manageable and is what I set out to do. I began researching the topic as a relatively ambivalent female in EE – I have never felt as though I faced discrimination – but I came away with a much deeper understanding of the situation here at Stanford and nationally. After speaking with a variety of people, from female Ph.D. students to the Dean of Engineering, and reading the survey responses of around 200 male and female Stanford EE students, I gained a greater understanding of current issues in the under-representation of women in engineering as well as their sources and possible solutions. The survey further showed that many students, both male and female, are surprisingly uninformed about the gender issue. This is my attempt to raise awareness by sharing what I have learned in the last few months.

Statistics

To put the situation in a numerical perspective, here are some numbers courtesy of the School of Engineering: Of the 69 B.S.E.E. degrees conferred in 2005-2006, 14.5% were female, compared with 14.2% nationwide.[1] 16.7% of full-time students working toward their Master's degree were female, while 19.6% of Master's degrees in EE were conferred to women nationwide.[2] Finally, 16.7% of full-time Ph.D. students last year were female, up from 13.16% in 2004-2005, compared to 13.5% of doctoral degrees in EE awarded to females nationwide. See Figure 1 for a graphical comparison.

Immediately, the number that stands out the most is the small undergraduate female population compared to the graduate population. It may seem somewhat counterintuitive that the percentage for undergraduate females would be lower than graduate females, since the trend is usually a decrease in females for each further advanced degree. However, this phenomenon is specific to undergraduate admissions at Stanford. Although prospective students usually designate a certain field that they are interested in, they are not required to select a major until the end of sophomore year. Therefore, the admissions department has little influence on how students divide themselves among different majors, unlike graduate school in which students apply directly to a department. These numbers indicate that Stanford is generally ahead of the curve in terms of the ratio of females in the electrical engineering department, but women remain underrepresented nevertheless. While the numbers put into perspective the lack of women engineering students, they do not paint the entire picture completely.

To get a better idea of the EE student mindset, I sent out an informal online survey, to which approximately 200 students responded. Keep in mind that the results are likely somewhat biased since it was a completely voluntary survey (thus the pool of respondents is self-selected). Still, after looking at the responses and chatting with some female graduate students and undergraduates, I found several recurring themes. Some issues dealt directly with faculty or the School of Engineering, so I approached them directly to allow them to respond to students' concerns.

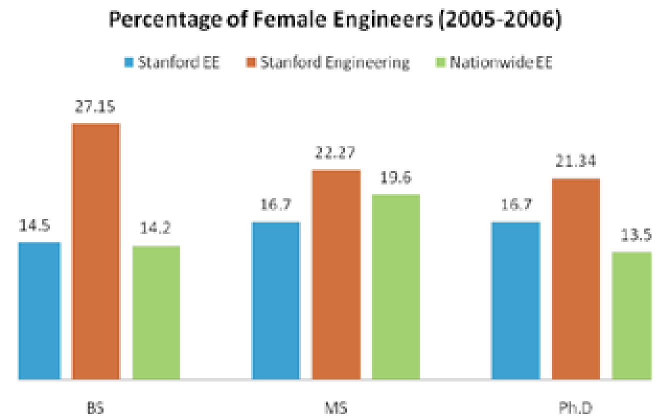

Figure 1: Chart of percentages of female engineers at Stanford and nationwide, by degree

A Problem Really Does Exist

A significant number of students, mostly male but also some female, expressed the opinion that having special opportunities for females, such as diversity fellowships and special admit weekends, is unfair and causes reverse discrimination. I called on Associate Dean of Student and Diversity Affairs in the School of Engineering, Dr. Noe Lozano, to respond to some of the students' comments. Dr. Lozano is extremely involved in encouraging minorities in engineering at Stanford and is a staunch supporter of diversity engineering groups. He immediately began by throwing out some numbers: "Everybody thinks it's the hard sciences and not engineering that are lagging, but when you look at the numbers, it doesn't pan out. Chemistry's almost 50% [women], Math is almost 50% nationwide, and Physics is approaching 50%. Definitely Biology now is majority women – 60% – guys are actually underrepresented in biological sciences… And then women, when you look at engineering, have actually gone up and gone down. So they were going above 20% nationally, or something like that for undergrads… in CS they were very, very high at one time, as high as maybe 30% - and they're back down again. So… it becomes very evident that engineering has a diversity problem. Definitely a gender one, besides race." The problem is that the low number of females in engineering is not necessarily a product of lack of interest. Instead, it is a result of a combination of social forces working against females that discourages them from entering the engineering field.

Even if equality and diversity were not issues, there is the simple problem of a lack of students in engineering in the United States. Dean Jim Plummer explained it more in terms of an economic problem: "If you really believe that innovation and entrepreneurship and so on is a competitive advantage for this country, going forward, then I think you do need to be concerned about the number of US students who are choosing science and engineering… and so in some sense the low-hanging fruit to help solve that problem is to get more women to be interested in careers in science and engineering."

What about some of the student claims? In response to the question of whether females in EE were discriminated against, one male wrote that there is "no need to make the gender ratio in EE 50-50, if women themselves don't want to come. Come on, there is no special support program to attract men to psychology, where majority of students are women. What's the big fuss

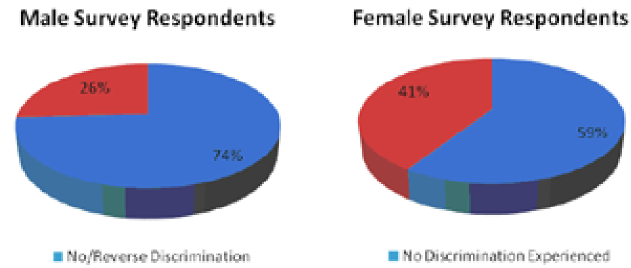

Figure 2: Perception of Discrimination by Gender

about all that in EE then?" Dr. Lozano responded, "I think that's a legitimate statement and that he's partially right, but there isn't an interest in increasing the number of males there in education or fields like that because men are not behind yet. They're so overrepresented that it's going to take another 10 or 15 years before males worry about being underrepresented." More than a handful of males also claimed they faced reverse discrimination, in which males are victimized by female favoritism, but Dr. Lozano immediately disagreed, saying, "No, I don't think there's a reverse discrimination issue…people think that because I have a 4.0 and somebody has a 3.7 and they got in, then they were being discriminated against, then they don't understand the academy; you don't measure talent by just GREs and GPAs, it's a threshold issue. They need to be certain level smart to compete at Stanford… reverse discrimination can only really exist once the playing field has been leveled, and because there's still underrepresentation, there's not reverse discrimination."

Many students will claim that the playing field appears "level." Females are offered the same opportunities to choose engineering; they take the same courses and the same exams, so if they choose not to do it or don't do well, that is of their own doing. However, things are not that simple; even a simple comparison between survey results from males and females shows some discrepancy. When males were asked whether they thought female EE majors at Stanford faced discrimination, only 25.8% mentioned the possibility of there being discrimination. The rest either said "No. Of course not," outright or claimed reverse discrimination. On the other hand, in the female survey in response to whether they had faced discrimination as EE majors at Stanford, 40.9% claimed that they had, as contrasted above in Figure 2.

As can be seen, many females have experienced discrimination, not necessarily in overt ways but in subtle and unspoken pressures and expectations. A number of psychological studies demonstrate the effect that expectations can have on a group's performance. World-renowned Stanford psychologist Claude Steele has studied "stereotype threat" for many years and has conducted many studies confirming this phenomenon, which has further been corroborated by studies by other researchers. Stereotype threat refers to the idea that, when a person's social identity (a group membership in a category like gender, race, or age) is associated with a negative stereotype, that person will tend to underperform in a manner consistent with the stereotype. One experiment studied the stereotype that men have stronger math abilities than women. When women were told that the math test they were to take would reveal gender differences, the men performed better than the women. However, when the test was not associated with gender, the two groups performed equally well.[3] This phenomenon can affect even the majority group, as seen in a separate study, in which white engineers performed far worse on a math exam when told that Asians typically outperformed whites on that exam.[4] Therefore, even for females who don't feel that they face any discrimination, there are unseen factors working against them in the very common expectation that women tend to excel less in math and sciences and are not as suited for engineering.

Another burden that women in engineering carry is the fact that they are still not viewed as individuals, a status that is much easier to attain as a member of a majority group. Dr. Lozano il-

"Have you ever faced discrimination in EE?" - Female Survey Respondents

◊ *Yes. Two examples (among many): My research advisor was 'sweeter' to me (than to any of the guys in the group – there was no other girl) when not discussing research, and stricter during research discussions. Once he commented that a technical report I had written had a 'female hysteric feel' to it – what he meant was that the writing was not technical enough. In conferences, I found it easier (than my fellow male colleagues) to approach senior (male) researchers and start a discussion. The catch is that they (the senior researchers) quickly switch the discussion from research to 'So, what do you do outside work?'*

◊ *In the first year of undergrad, I was told by a couple of male classmates that it was normal for me to be successful in homeworks and exams, but that I would never be good at designing/implementing circuits/systems. Other than these type of specific cases, I sometimes get the feeling that 'less' is expected of me in this field, and that people are okay if I achieve little. I never felt this way in undergrad, but have been feeling this since I came to Stanford for grad school.*

◊ *While I have not encountered blatant discrimination, I feel that I am often perceived as less intelligent by both my peers and faculty members because I am female. I feel like I have to do more to prove myself to them.*

◊ *I have at times felt that women aren't taken as seriously, or that we need to prove ourselves more. I remember one prof who would react differently to questions depending on the student. To female students, he would just give the answer. To male students, he would tell you how to find the answer. For projects working together with male students, I find that sometimes they aren't too enthusiastic about working with women.*

◊ *Only that I'm not as smart.*

lustrated this point with an example: "If I were a white guy in a class and I'm failing, I don't bring down all white guys if I fail. But if you're a woman, it's a group identity, and so part of what women are carrying is that group identity that guys don't have to worry about." Some responses in the female survey agreed with this view, such as, "I just always wanted to prove myself as competent, and felt that any time I wasn't, it reflected badly on all females."

To make the discussion even more complex, here is a surprising fact: on average, females have higher GPAs than males, even in engineering studies. After many years of advising minority engineering students at Stanford, Dr. Lozano has seen a huge disparity in the way males and females respond to academic difficulties. He related that "Guys tend to blame their professors and others, women blame themselves, and they also don't realize that the guys they are competing against have lower GPAs, because they sound so much more confident and on top of their game, and sometimes they have a 3.4, and the guy who sounds like he's on

What can Stanford do?

◊ **Give the faculty more incentive to interact with their students, or have the particularly skilled professors teach workshops.** "I think we just need to have more faculty develop [social consciousness or cultural competence], and I think we need more faculty resources to do that. So create some resources, either incentive research funds, fellowship funds, teaching funds," suggested Dr. Lozano.

◊ **Increase the number of female faculty.** As Professor Goldsmith explained previously, having mentorship for female graduate students who show promise is one step that can be taken. On a broader level, we need more females in the math and science fields, which requires outreach programs for young girls who enjoy math and science. For women who have (or want) kids and become professors, Professor Goldsmith had a few suggestions for how the path to becoming a professor could be improved:

> *Giving time off from teaching for the first year with a new baby would be helpful (extending the tenure clock is more of a punishment than an enabler, at least for most women professors). Having emergency on-campus childcare for when kids or nannies are sick, and more childcare on campus, perhaps including afternoon care for older kids, would be helpful. Making people sensitive to scheduling faculty meetings very early or late in the day would be helpful. Having a fund to subsidize taking nannies or spouses to conferences to watch the kids would be helpful. But these are all ways to make it easier for women with kids to be professors. We have to get women (with or without kids or kids-to-be) to think about being a professor long before they get to the end of graduate school, and we have to have more outstanding women on engineering faculties to provide role models and mentorship.*

◊ **Increase the number of diversity fellowships, or focus solely on women in the EE department.** Several of the female EE students who responded that they had considered leaving the EE major cited that thoughts of leaving occurred during "grad school at Stanford due to lack of funding." As Dr. Lozano says, "If you're a minority and you're not funded, it tells you something indirectly."

◊ **Increase community within the EE department and the Engineering community in general.** Give students more incentive to go to "mixer" events – not just pretzels and M&M's. We're busy by nature, and unfortunately it'll take more than a few snacks to get us to put our assignments aside. Another suggestion is to have some kind of student-organized newsletter for engineering students. Just something entertaining and informative that lets us know what is going on in other groups, what events we should go to when we're not in lab, and a focus on student well-being.

◊ **Attract and retain more undergraduates.** Some students had the suggestion to "create more interesting and fun intro-EE classes other than frosh seminars." I whole-heartedly agree. The period of time when students are most likely to drop out of EE is during sophomore year while slogging through EE core. At some point, most students ask themselves why they are doing what they are doing. If they haven't been inspired yet by some of the cool applications of EE, it is hard to be motivated by just the Fourier Transform or the transistor itself, although one person did claim he chose EE because "I love transistors!!"

◊ **Support your students.** In general, many students felt that the "EE department is not doing enough to support its students, period." Even Dean Plummer admitted that the EE department seems to be on one end of the spectrum in terms of planning and holding events for the department. It is only recently that they even began to have faculty lunches. This is an area that students must be more vocal about and demand the support they need. The survey indicated that many students have considered leaving the EE major: 45.3% of females and 40.7% of males – these are very high numbers. For many, this wasn't a one time fleeting thought. When I asked when students had considered leaving, some responses were: "Every now and then," "All the time… the 'what else is there?' question is what kept me here," "Now. A bit tired of Stanford EE." These discouraging remarks indicate issues within the department itself and emphasize the need for students to be supported and mentored more in general. Keep in mind that these are responses of students who are still in EE and don't include students who have already left the field.

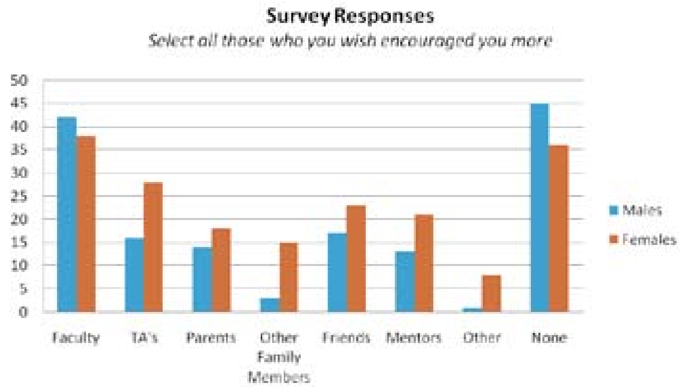

Figure 3: Detailed survey responses to who students wished encouraged them more in engineering

top of it has a 2.9 or 2.8, yet the women have different expectations… there is a stronger tendency for women to move away from the field when they're doing like a 3.0 or 3.1… a guy would never have that kind of conversation unless they were really about a 2.5 or a 2.4." This may be the result of social constructs, in which females feel the need to prove themselves more than males, particularly in a male-dominated field like engineering. There are innumerable ways in which women are at a disadvantage, starting with subtle biases from a young age. Increasing the knowledge of the effects of stereotype threat and other biases in hindering the true capabilities of women is an important step in encouraging females in engineering.

The Importance of Role Models and Mentorship

Now that the existence of a problem has been established, what are its causes? A recurring theme in virtually every conversation was a lack of role models and faculty mentorship. In general, students expressed a common desire for more faculty interaction and involvement. "I wish I felt more comfortable with my professors. I've found sometimes in other majors your professor will want to know more about you than I feel most EE professors do. And I'm totally convinced they're just as nice and concerned, but for whatever reason – their personality, or just the way it is – they don't really reach out to know their students on a personal level," explained senior Gloria Lin. For students like Ph.D. candidate Hrefna Gunnarsdottir, who still remembers when a professor first thought she was capable of getting a Ph.D., a faculty member made a difference in who she is today: "I don't think professors in perhaps undergrad are conscious of the fact that if they say something to a person like 'You would be good for grad school', it *really* matters. Because it means that someone's taken the time to look you over and form an opinion of you and say, you know you can do great things. So it would be good if undergrad professor and even graduate professors were like, 'I see potential in you.'" Moreover, this is a wish that spans across both genders. In the online survey, the most common female response to the question of who students wished would encourage them more, was faculty, at 38%. Males had an even higher proportion who wished there were more faculty encouragement, at 42%. See Figure 3 for more responses to this question.

More specifically, the lack of female role models in engineering plays a major role in the low percentage of women engineers. Most of the females in EE that I spoke to had someone in their family who was female and an engineer, or at least in a math-related field. In the university setting, undergrads see the same small percentage of females in grad school, and all the students see the dearth of female faculty in EE, and the cycle continues as even Ph.D. students become discouraged from entering academia. There are only four female EE professors (excluding those with courtesy appointments) out of 65 total faculty members – that's less than 7%! As one female survey respondent lamented, "I do feel a lack of role models. I haven't had a *WOMAN* technical (Math/Sci/Eng) teacher or professor since 8th grade. I know it takes a while to have women 'trickle' into these positions, but I really wish I had had one."

The lack of female faculty members is not simply a factor of low numbers; there are other obstacles involved. EE Professor Andrea Goldsmith, who was in e-mail correspondence while working at a startup, had a few suggestions on how to encourage more females in engineering to become professors:

Some ways to do this include identifying promising women as undergraduates and graduates and grooming them to think about becoming professors. This can be done through mentoring and tracking them as they go through their degrees. Making sure subtle bias doesn't make its way into decisions by search committees is extremely important (and challenging). Having more flexibility with faculty billets would also be good, as searches are usually targeted to a particular area and the likelihood of an outstanding woman graduating in a given year in a given area is small. Thus, having more flexibility with billets so a position could be offered to a truly outstanding woman regardless of her area would be good.

At a visionary level, we need to encourage more girls/women to pursue science and engineering, from preschool on through elementary school, middle school, high school and college. The subtle bias kicks in very early. This is a very difficult issue that requires national commitment and funding.

Another obstacle for female faculty is that they are sometimes perceived as being more "hardcore" or unapproachable than their male colleagues. "I feel like they have this understanding within themselves that they… juggle much more than their male counterparts so they can't help but bring it out in the way they interact with their students," theorized Ph.D. candidate Kamakshi Sivaramakrishnan. Professor Goldsmith responded by attributing this to being part of the "subtle bias" that affects females in engineering: "Of all the men and women faculty I know at all universities, the women on average are more approachable, provide more service to the university and broader technical community, and spend more time mentoring their undergraduate and graduate students than their male counterparts (and they typically have the lion's share of the kid responsibilities at home too). Unfortunately, this is not rewarded much; it is rather expected of women more than men, so when the expectation is not met, the woman is described as hardcore and tough… When men are described as hardcore and tough, which is fairly rare, it is generally a compliment. Surviving and thriving in academia is difficult. We all are extremely busy, and often don't have as much time for non-essential things as we would like. Women faculty members are penalized for this more than men. We should try to find a way to eliminate this dynamic." These are difficult issues to tackle, since they are a common undercurrent of thought, yet the source is difficult to pinpoint. The most important thing is to stay informed and to remain open-minded.

Lack of Community within EE Department

Like many of the issues above, the lack of community within the EE department is an issue that expands beyond just women in engineering and encompasses both males and females alike. Students on the whole seemed to feel that there was a lack of a feeling of community within the department. As Gloria Lin pointed out, "I think overall just a stronger sense of community within the major would help. I've seen the same people in like 12 classes by now – I sort of know them and I see them very often, more often than I see my drawmates, but I don't really know them, like where they grew up, who they are, what they're interested in." Several grad students shared this sentiment, qualifying that this may be the experience on the 3rd floor of Packard only, and could be very different in other areas of the department: "We don't really know what's going on elsewhere. Like, we hardly know what's going on in the basement of this building!" said Gunnarsdottir with a smile. In one suggestion regarding what else the department could do, one male respondent answered that he would like to see more of "funding events for networking. In general I feel the department doesn't help anyone, man or woman, in socializing with the rest of the department. Can't they give students some money for beer or food once a week? Every other department has something funded, and we're stuck in the cold with a tiny cooler of our self-funded beer. It is sad."

As the Dean of the School of Engineering, Dean Plummer is aware of this and hopes that a new building will help create more community. You may have received an e-mail with a survey about a new engineering building being built with more space focused on students. Dean Plummer believes that some of the problems with trying to hold "mixer" events have been a direct result of not having an appropriate location or setting. The "new Terman," as depicted in Figure 4, will have student spaces that will encourage students to work together and hopefully create more of a community. However, whether this will be successful in encouraging a tighter knit community is uncertain, and the building will not be completed for another few years.

References:

[1]National Science Foundation, Division of Science Resources Statistics, special tabulations of U.S. Department of Education, National Center for Education Statistics, Integrated Postsecondary Education Data System, *Completions Survey*, 1995–2004.

[2]National Science Foundation, Division of Science Resources Statistics, special tabulations of U.S. Department of Education, National Center for Education Statistics, Integrated Postsecondary Education Data System, *Completions Survey*, 1995–2004.

[3]Spencer, S, Steele, C, Quinn, D, (1999). "Stereotype threat and women's math performance." *Journal of Experimental Social Psychology*. 35, 4-28.

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Erin Hsu is a coterminal student at Stanford in Electrical Engineering.

Figure 4: A sketch of the proposed engineering building

What can we do?

- ◊ **Stay informed.** Some survey respondents, men and women, had no idea what women in engineering groups were doing and didn't care, yet called foul claiming there was reverse discrimination. Try to be open-minded and understand what is going on around you. Things are often not as they appear on the surface level. Don't jump to conclusions. Try to understand situations before you call them something else.

- ◊ **Be vocal.** There were many complaints in the survey responses, but nothing will be done without taking initiative. If you want more funded events, stop by Dr. Bruce Wooley's office. Dean Plummer himself requested more student input, saying, "It's very hard to top-down manage things at a university, so I think the best kinds of things happen when there's kind of a bottom-up upwelling of support to do something."

- ◊ **Be supportive of women in engineering groups.** Many students did not know what groups like SWE and WEE did, and others thought they were unfair. Go check them out before making that criticism.

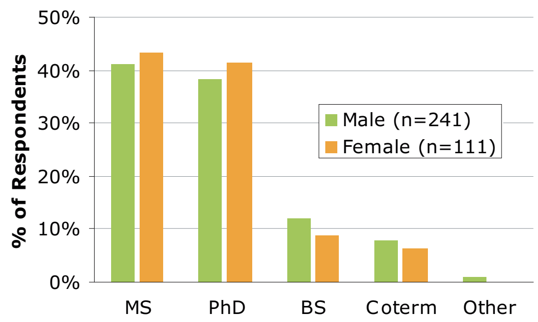
- ◊ I am a member of SWE, and unlike what some people think, we do not sit around a table and discuss all the ways we are discriminated against, nor do we disdain our male classmates. Instead, we attempt to create a community and to spread knowledge like the issues mentioned in this article. We bring in female role-models from industry to speak about their experiences, and we focus heavily on reaching out to the community so that young girls know they can also be cool Stanford engineers someday. We have elementary school, middle school, and high school outreach events throughout the school year (and we always need volunteers!), and we have a multi-tiered mentorship program, hold majors lunches, and now offer corporate-sponsored scholarships. There is nothing exclusionary about the relevant corporate speakers every week, free food, and community service opportunities. Grad students are welcome and even desired. We also welcome male members and have several male officers, who are very supportive of women in engineering. Stop by and check it out – we have meetings during lunch every Wednesday in Terman 556.

- ◊ **Be a role model.** Encourage young people that they can do anything they want. Tell them the cool things you can create as an engineer, and make sure they know they can do it if they put their mind to it.

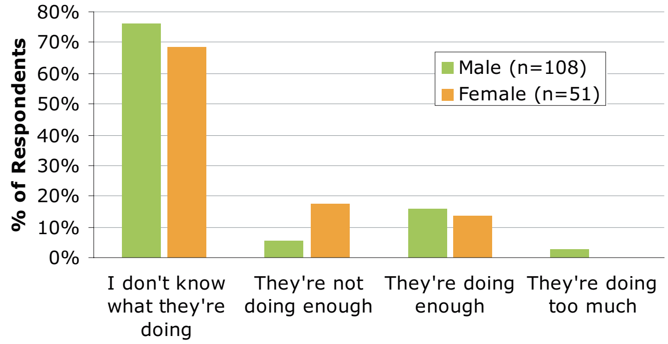
- ◊ **Be more confident.** Finally, this advice applies mostly to female engineers. I hope the information in this article has shown you that there are others in the same situation as you, and that you are just as capable (if not more so) than that guy who always raises his hand and asks questions in class. Be empowered; don't lose your confidence. If you do poorly, don't internalize it and blame yourself.

Survey Results

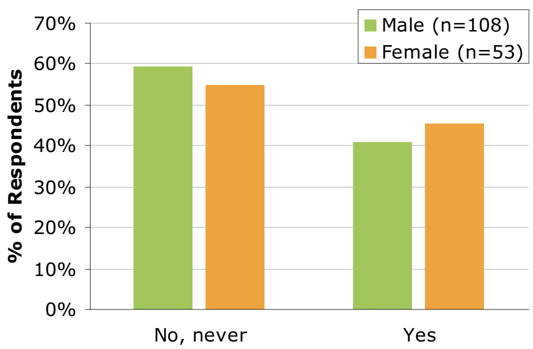
What degree are you pursuing?



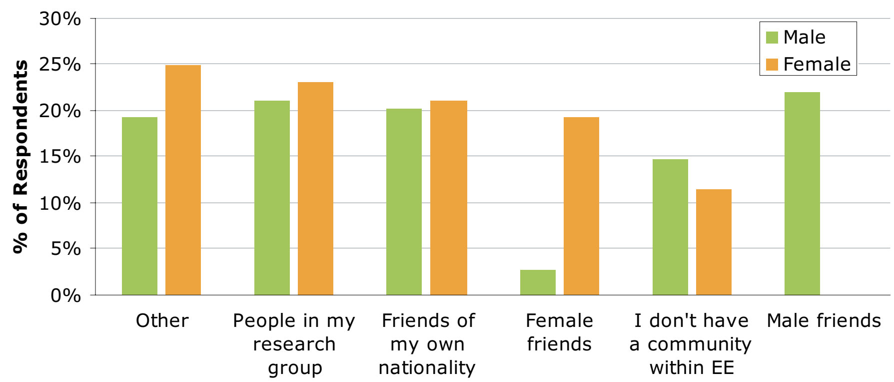
How do you feel the EE department is doing in terms of supporting women in engineering?



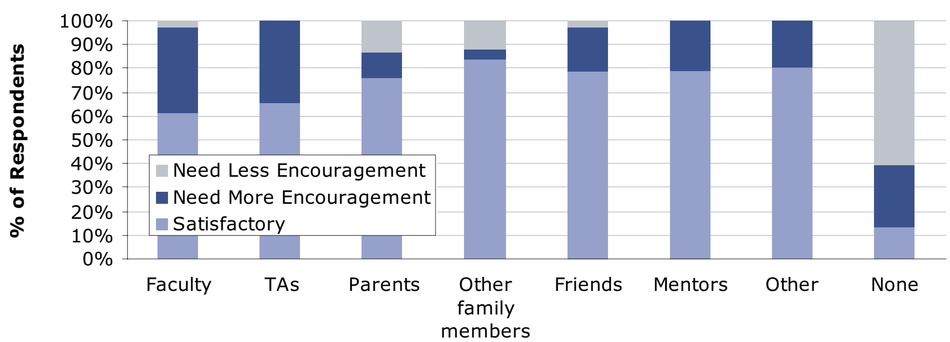
Ever considered leaving the EE major?



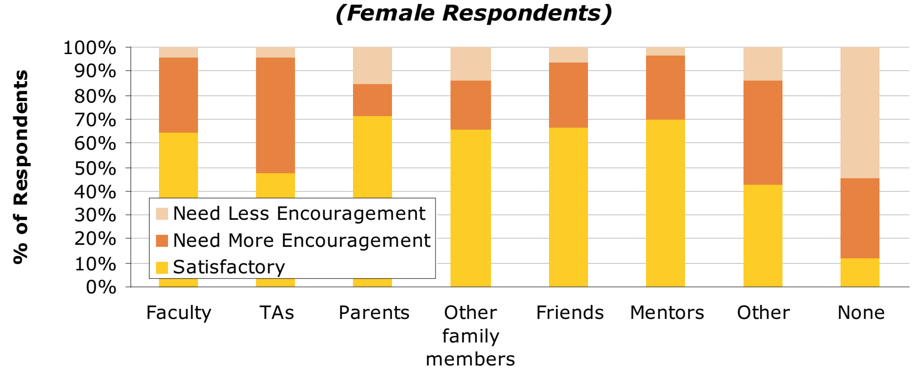
Who do you consider to be your closest community in EE?

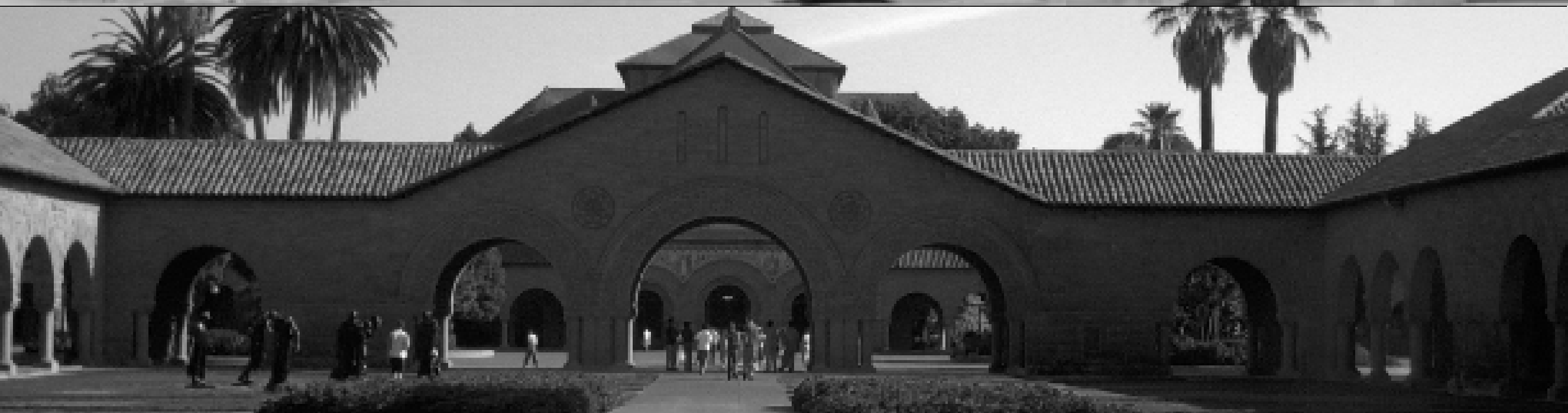


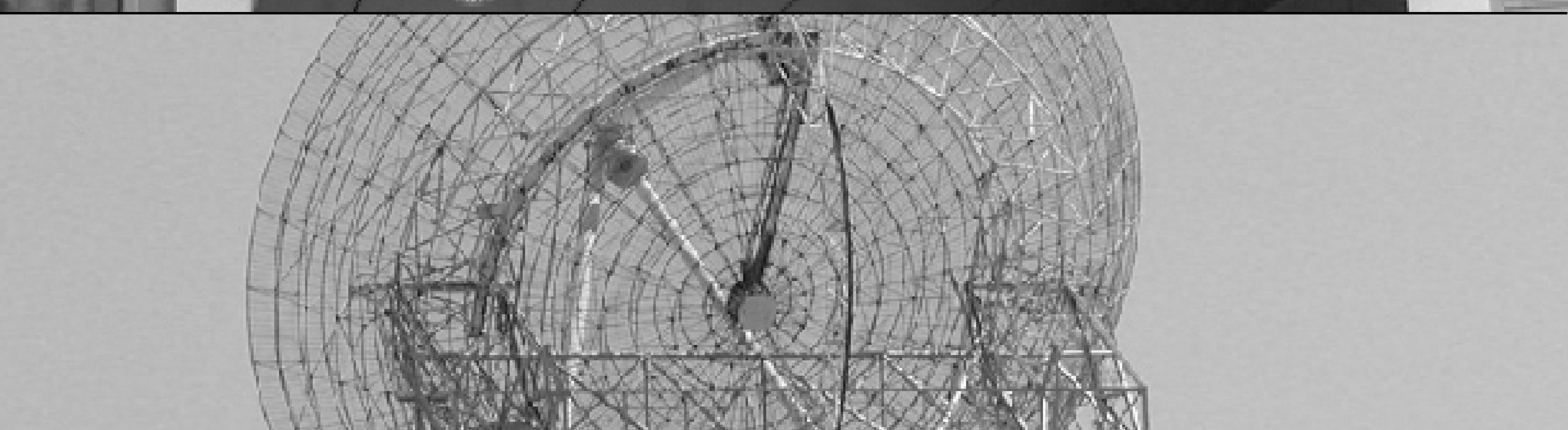
Views towards encouagement received from group (Male Respondents)



Views towards encouragement received from group (Female Respondents)







The Evolution of the Stanford M.S. EE Program

How Silicon Valley and Stanford molded the modern MS program

By Omair I. Saadat

Introduction

The Stanford Electrical Engineering Masters (MSEE) program is very much a product of the co-evolution of Stanford and Silicon Valley over the past 50 years. Ever since Fred Terman, the visionary engineering dean and provost, encouraged corporations to move to what is now known as Silicon Valley, Stanford has had intricate ties with the industry. The Stanford EE department's MSEE program is a product of this close relationship with corporations in the valley.

Size of the Program

MSEE's student enrollment has grown by a factor of 5 over the past 55 years. The MS program crossed the threshold of 100 degrees granted in 1958, due to both increasing enrollment from industry and increasing numbers of students pursuing doctoral degrees across the nation. Interestingly, the number of students at Stanford intending to pursue a terminal masters degree remains far larger than the number of students intending to pursue doctorates. The following graph shows the number of masters degrees granted in comparison with doctoral degrees granted by Stanford.

Influence of Industry on MS Program

In the early 1950s, local companies like Hewlett-Packard asked Stanford to provide their engineers the opportunity for further professional development through taking graduate level courses at Stanford. In response to these demands, Fred Terman, who was the dean of engineering at the time, launched the Honors Cooperative Program (HCP). Under the HCP program, companies would pay twice the normal tuition in order to have pre-selected employees enroll in the MSEE program as long as they met admission standards. While there was some initial controversy over the admissions process, the large profits from the HCP convinced the Electrical Engineering Department to embrace the program (Lecuyer 2002).

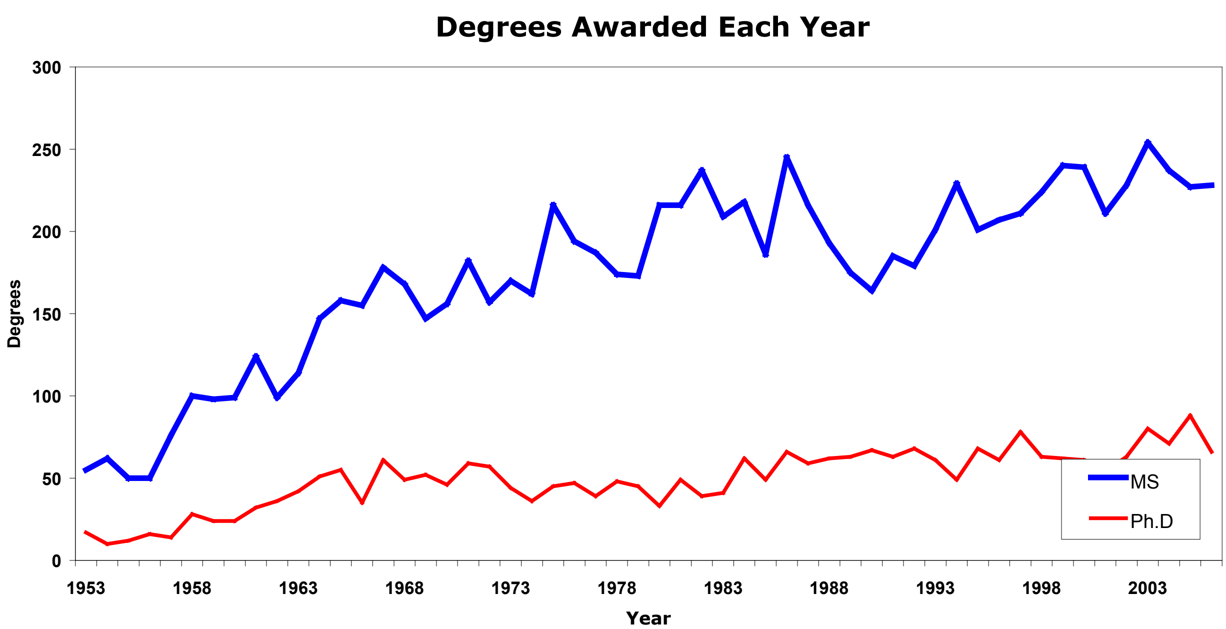
During the 1960s, demand increased for remotely offered

Figure 1: Stanford's David Packard Electrical Engineering Building

courses where employees could take Stanford courses without leaving the workplace. In response to these demands, Stanford launched the Stanford Instructional Television Network (SITN). SITN courses were recorded and broadcast via television to local companies. The SITN courses evolved into online courses offered through what is now known as the Stanford Center for Professional Development (SCPD). Not only is this program successful among engineers in the valley, but the availability of SCPD courses via online webcasts has proven immensely popular among enrolled undergraduate and graduate students alike.

Evolution of the Master's Program

The MSEE curriculum has continually evolved since the 1950s. In 1952, courses focused on topics such as power systems, illumination, vacuum tube electronics and radio communication. Over the next ten years, the Electrical Engineering Department underwent substantial changes. Faculty members such as John Linvill, who was recruited from Bell Laboratories for his exper-



tise in solid state electronics, "transistorized" the curriculum in the late 1950s by moving the curriculum away from studying vacuum tube based circuits to transistor based circuits.

By 1966, most of the elements of the current MSEE program were in place. They included the requirement of a 45 unit masters with 9 units of 300 level courses, the choice of one depth area with three courses in addition to coursework in three other distinct areas. While there have been modifications to the depth areas, the basic structure of the masters program has not changed over the past forty years. Most notably, there are no requirements for MSEE students to take courses outside the department.

Finally, in recent years, there have been changes in admissions with the introduction of a new masters-only admission track. Also, a new committee has been commissioned by the department to reevaluate the MS curriculum in light of recent changes in industry and in electrical engineering discipline.

Impact of Stanford MS Program on department

The Stanford MSEE program, by virtue of its large size, has had a great impact on the character and composition of the Electrical Engineering Department. They have brought many benefits to the department. First, the MSEE program, especially the SCPD program, is a good source of revenue for the department, which pays for the teaching staff. Second, the large number of students and the large faculty size translates into a great breadth of courses, which benefits doctoral students and undergraduates alike. Third, the large MS program gives the department a large pool of potential doctoral students to from choose from. Given that the student pool at Stanford is much larger than at peer institutions, professors are able to identify students with research potential that was not conveyed through test scores, transcripts, or application. Finally, the large MSEE program creates a strong alumni network for current students and the large number of MSEE alumni strengthens bonds between Stanford and industry.

At the same time, there are some drawbacks to a large masters program. First, according to some professors, the quality of grad courses is somewhat sacrificed to accommodate the large class sizes in comparison to other graduate departments at Stanford. For example, introductory graduate level courses such as EE 214 or EE 216 have enrollments approaching 150 people. These professors feel that graduate courses at peer institutions are more focused and intense because the class sizes are smaller and the pool of enrolled students is more self-selective, i.e. doctoral students with clear intentions of conducting research in the discipline. Second, a large MS program has an adverse impact on first year doctoral students. For instance, it is harder for doctoral students to get funding and be involved in a research lab in their first year simply because resources are strained. Third, the large MS enrollment makes a thesis requirement impractical. About 200-250 MSEEs are awarded every year. Given that there are approximately 65 EE faculty, this would translate into each professor supervising 3 to 4 MS theses annually. This would simply be a logistical impossibility. In addition, requiring a thesis would make it much harder for remote SCPD students to complete their degree requirements. While a MS thesis would not be ideal for terminal MS students, it would be really beneficial for students intending to go on to the Ph.D.

Comparison to Peer Institutions

The Stanford MSEE program is significantly different from the Master's programs offered by two of Stanford's peer institutions, Massachusetts Institute of Technology and University of California at Berkeley. The MIT EECS department offers two different Master's programs: the Master of Science (SM) program and the Master of Engineering (MEng) program. The Masters of Science program is targeted for students intending to pursue a doctorate degree. As a result, admission to the SM program is only granted to students considered to be capable of doctoral study (Penfield 1998). On the other hand, the MEng program is for MIT undergraduates who wish to pursue a terminal masters degree in electrical engineering. Another point of distinction is that the MIT masters programs require the submission of a thesis, unlike the Stanford MSEE program. UC Berkeley has a similar philosophy to MIT in that the MS program is primarily for students intending to perform research for a Ph.D. rather than a professional degree. Thus, given that both UC Berkeley and MIT require these for their Master's, graduate students are expected to join research groups in their first years.

Potential Changes to MSEE Program

The Stanford EE department has commissioned committees to look at both the MS and Ph.D. programs to see how they can be improved. While these committees have not completed their work and thus their findings are not public yet, the following proposals might be beneficial for both the MS and the doctoral program.

I believe the department should create two separate tracks within the MSEE program. While one track would solely be a professional degree, the other would be a more research-intensive track would be for students intending to pursue a doctorate. The professional MSEE program would provide students with technical background necessary for many industry jobs, while the research MSEE program would be geared towards getting students involved in research as soon as possible. Thus, the research MS program would have a thesis component in it, similar to the MS programs at Berkeley and MIT. A thesis requirement would force professors to accept first year students into their labs, and therefore alleviate the problem of doctoral students having a hard time getting into labs.

Figure 2: MIT's Stata Center

Figure 3: University of California, Berkeley

My second suggestion would be that the EE department should strive for interdisciplinary strength by requiring students to take courses outside the EE department. A salient strength of Stanford's that sets it apart from its peer institutions is its competence across a breadth of disciplines. It would be a waste for electrical engineering students and the department not to leverage this advantage.

Conclusions

The large size of the Master's program at Stanford has benefited the department and its students in many ways, but at the same time, has a few shortcomings, especially compared to similar programs at MIT and Berkeley. The biggest advantage for Stanford is that the large output of MSEE graduates has created strong ties between Stanford and local industry. In addition, programs like SCPD are good sources of income for engineering departments. However, these benefits have come at some costs. The most significant problem is that the large numbers of Master's students sometimes overshadow the needs of students who intend to pursue doctorates. Finally, graduate courses are often larger than comparable courses at other institutions, leading to a less personalized education. A two-track Master's program that caters to the specific needs to these two distinct demographics may go a long way towards improving the environment for first year doctoral students.

Acknowledgements

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HCI poses interesting new challenges for researchers across the globe. At Stanford, the energy within the HCI community is contagious. Problems that researchers are trying to solve include whether the answer to better technology is always faster and more complex, and whether the desktop paradigm is the only way to represent the organization and interaction with the personal computer. In addition, the dynamic world of today forces us to consider how technology can be adapted to the needs of the Third World, and what challenges are posed by the mobile knowledge worker of the future. With the recent establishment of the Hasso Plattner Institute of Design, commonly referred to as the d.school, students and faculty alike are encouraged to imagine the world as a "prototype," engaging in good practices and processes in order to ensure that design problems are solved through observation. As Prof. Klemmer aptly notes in Inter-Action: "Perhaps civilization's biggest screw-up came when Rene Descartes said, 'I think, therefore I am,' separating mind and body. What Descartes didn't know is that it's all happening in the interface.

All The World's An Interface

Understanding Human-Computer Interaction

By Amal Dar Aziz

Background and History

Human-Computer Interaction (HCI) is a relatively young field in computer science, rapidly growing with exciting research both at Stanford and globally. In recent years, the importance and significant impact of HCI has been demonstrated by, among other things, the wildly successful iPod and various social networking websites such as Facebook.

Advocates of interaction design Alan Cooper and Robert Reimann write in *About Face 2.0: The Essentials of Interaction Design*: "Even as technology frees us to perform great feats of invention, it simultaneously ties us to ways of thinking that are contrary to the natural expression of human behavior." Bill Moggridge, a British industrial designer and co-founder of the well-respected design firm IDEO, first coined the term "interaction design" in the 1980s. In introducing this term, he was referring to the growing need to place users' critical needs at the center of design thinking. Besides addressing the challenge of creating complex, intricate technologies required to meet the demands of computing today, engineers and interaction designs have to deal with the equally, if not more imperative, issue of making "powerful technology fit easily into people's everyday lives" (Moggridge xi).

Since Gillian Crampton Smith established the Computer Related Design Department at the Royal College of Art in London in 1989, the precedent was set for computer science and design departments across the world, resulting in a growing number of departments focusing on human-computer interaction. As a result, the terms "HCI" and "CHI" are quickly asserting their presence in the world of high-tech jargon, though many engineers are not quite sure what these strange acronyms of interaction design mean and what they entail. For the purpose of increasing awareness and sharing knowledge on this field, the annual CHI conference attracts interaction designers and researchers from across the globe to discuss human factors in computer systems. This year, CHI celebrates its twenty-fifth anniversary. With CHI's constant expansion of membership and attendance, indeed, "CHI is at the center of the most interesting problems in modern computing." [1]

How HCI Fits in Computer Science

Human-Computer Interaction (HCI), or Computer-Human Interaction (CHI) is defined as the study of i) how people interact with computers, and ii) to what extent computers are or are not developed for successful interaction with human beings. It is dedicated to minimizing the barrier between human cognition on the one hand, and software and hardware on the other. Professor Scott Klemmer, co-director of the Stanford HCI Program within the Computer Science (CS) department, further elucidates that HCI is different from any other area in Computer Science. Traditional CS "studies people acting through technology… for much of computer science, the metric of success is the system [speed, capacity, etc.]" while for HCI the subject of concern is the user experience itself. What may make sense to the engineers is not necessarily intuitive to the average technology users. It is specifically for this reason that the study of HCI is essential.

Figure 1: Apple's iPod

Many consider interfaces like Apple's sleek and popular iPod or Google's home page as embodiments of the central dogmas of strong interaction design. They are simple and intuitive, draw emphasis to the central components of the interface, and afford ease of use for both novice and expert users. For example, a first-time user should be able to understand how to interact with the interface with little guidance, and the expert user should feel comfortable using keyboard shortcuts and accomplishing more difficult tasks with relative ease. Metaphors relating to tangible, everyday concepts, such as the desktop, are often used to make technology more comfortable and intuitive. Comparing to when Apple first introduced the Macintosh in the early 1980s, requiring users to send their disk icons to the "Trash" on the desktop Graphical User Interface (GUI), our understanding and appreciation of HCI have come a long way.

HCI Research at Stanford

Here at Stanford, the HCI group is led by CS Professors Terry Winograd and Scott Klemmer. The research group takes on projects varying from Gaze-enhanced User Interface Design (GUIDe) and Gestural Interfaces, to the d.tools project[2], which enables rapid off-the-desktop prototyping. They share various collaborations with departments across the campus, such as the Center for Design Research and Center for Computer Research in Music and Acoustics (CCRMA). Several of these projects are described here.

Digital Collage

Suppose you are a field biologist, conducting research that necessitates both written notes as well as digital pictures to record sightings in the new territory. Is there any easy way to combine these two physical artifacts, and share results with your fellow researchers, without losing track of one's notes? Graduate HCI students Brian Lee and Heidy Maldonado are trying to answer this question in order to realize the potential to integrate "technology into design activities and education."[3]

ButterflyNet

Students in Professors Scott Klemmer and Bill Verplank's HCI Design Studio course this past Winter quarter used pens and notebooks to narrate their own design concepts using the research team's ButterflyNet software, Flickr, and special lined notebooks and digital pens, to form a digital collage of their concepts.

Diary Snippet

Another example: Imagine that as you walk to class, an interesting idea for a digital prototype comes to mind. There's no time to pull out the idea log from your backpack and jot the thought down while it's fresh in your mind without being late to class – what should you do? Graduate HCI student Joel Brandt explored this concept last quarter in his "Diary Snippet" research, in an attempt to understand how users could use their cell phone – an almost necessary device many of us carry every day – to record

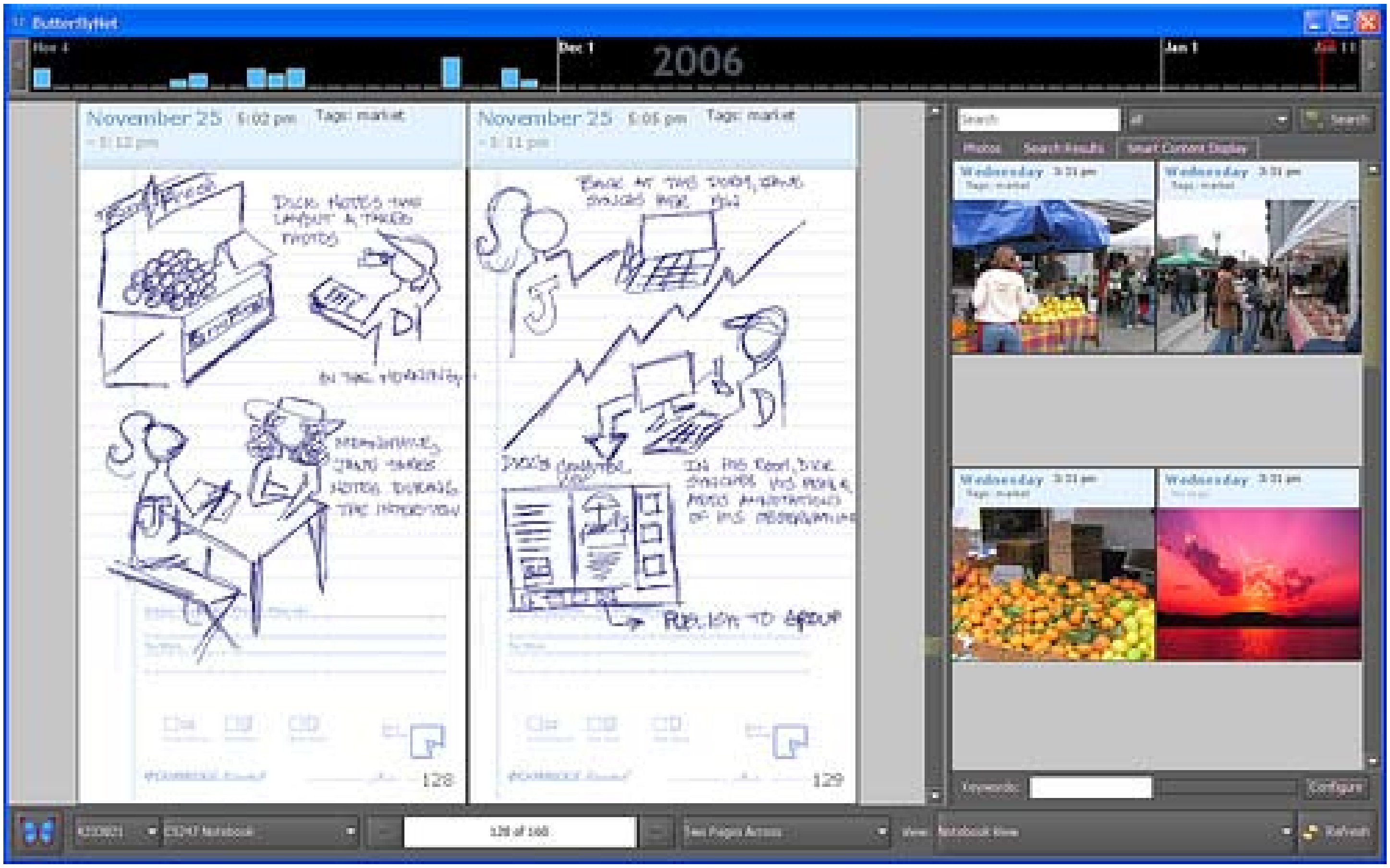

Figure 2: Example of ButterflyNet Interface

ideas in the form of text messages, voice recordings, and pictures. He then compared this form of diary use to the traditional written form of diary, and discovered that the majority of users found it easy to track their ideas on the go with their cell phones. This finding was recently integrated into ButterflyNet, allowing users to send their ideas via their cell phones, and then synchronize these "snippets" with their digital diaries.

Research Beyond Stanford

Yet another intriguing example of HCI research is the focus on gestural interfaces. The Nintendo Wii is a great example of how interfaces have become more intuitive, mimicking real-life situations. Users playing Wii tennis must actually position their bodies in a backhand position in order to hit the virtual tennis ball over the net using their virtual tennis rackets.

Outside the scope of gameplay, Stanford HCI researchers are exploring the way gestural interfaces can be used to break away from the two-degrees of freedom paradigm set up by the mouse and other pointing devices. Though the rapid development of graphics, users are able to view increasingly complex three-dimensional surfaces. Though it is possible to use a pointing device to navigate through a scene and manipulate the three dimensional surfaces, it certainly is awkward and difficult to do so. Thus, many researchers, including those at Stanford, are exploring new ways to manipulate objects represented on GUIs through hand gestures in a manner that makes use of gestures used by the average human being in order to manipulate physical objects.

Dan Phiffer and Mushon Zer-Aviv have pushed this concept to explore new ways of navigating in Google Earth and other 3D mapping applications, and have developed AtlasGloves, a do-it-yourself hand gesture interface. The user interface is composed of illuminating gloves which are used to track gestures such as grabbing, pulling, reaching and rotating[4]. For an example, one can use his or her non-predominant hand to delineate the axis along which the earth must rotate, and the dominant hand to specify the angle of rotation. Understanding the roles one's dominant and less dominant hand play when manipulating physical objects is essential in order to maximize the advantages of manipulating interfaces through gesture. For an example, users typically perform

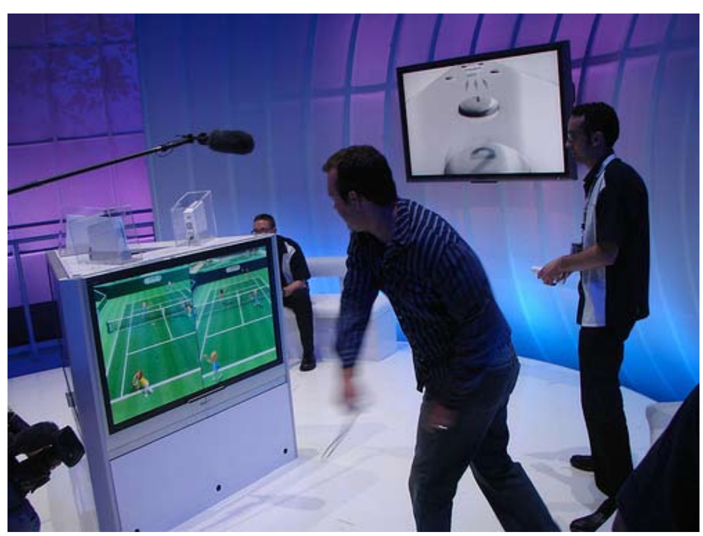

Figure 3: Playing with the *Wii*

Figure 4: Gestural Manipulation

Figure 5: Example of AtlasGloves use

actions with their dominant hand (e.g. writing) and direct the action with the less dominant hand (e.g. positioning and rotating a sheet of paper while writing).

Food for Thought

HCI poses interesting new challenges for researchers across the globe. At Stanford, the energy within the HCI community is contagious[5]. Problems that researchers are trying to solve include whether the answer to better technology is always faster and more complex, and whether the desktop paradigm is the only way to represent the organization and interaction with the personal computer. In addition, the dynamic world of today forces us to consider how technology can be adapted to the needs of the Third World, and what challenges are posed by the mobile knowledge worker of the future. With the recent establishment of the Hasso Plattner Institute of Design[6], commonly referred to as the d.school, students and faculty alike are encouraged to imagine the world as a "prototype," engaging in good practices and processes in order to ensure that design problems are solved through observation. As Prof. Klemmer aptly notes in Inter-Action: "Perhaps civilization's biggest screw-up came when Rene Descartes said, 'I think, therefore I am,' separating mind and body. What Descartes didn't know is that it's all happening in the interface."[7]

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[1]http://www.chi2007.org/welcome/anniversary.php

[2]More information on d.tools at: http://hci.stanford.edu/research/dtools/

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[4]For Atlas Gloves information and open source code, visit: http://atlasgloves.org/

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[6]Learn more about d.school: http://www.stanford.edu/group/dschool/

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Return of the Dragon

The Scientific Promise of China

By A.J. Minich

As the rocket lifted off into the dusty skies of Sichuan Province last November, a wave of collective pride reverberated throughout China. Inside was China's first domestically-designed global communications satellite, Sinosat-2, which was destined to broadcast the 2008 Olympics in Beijing straight to homes throughout East Asia. As it soared through the air, Sinosat-2 seemed to represent China's past and upcoming technological achievements in the 21st century.

Humiliation and Failure

Upon reaching orbital altitude, however, the satellite failed due to malfunctions in the antenna and solar panels. After days of diagnostics, engineers at the Chinese Academy of Space Technology declared the satellite irreparable. Soon thereafter, China decided to launch a similar satellite – Sinosat-3 – in early 2008, but the new model is much less advanced and will be unable to deliver broadcasts to as many viewers. Meanwhile, Sinosat-2 will float in space as a lasting reminder of what could have been.

As one can imagine, the spacecraft's failure has proved a great humiliation for China. Aviation Week calls it "the worst spacecraft failure in the history of the Chinese space program." The Chinese government itself has labeled the failure as a 'national embarrassment' and will probably conduct a large-scale 'rearrangement' at the state-owned Academy of Space Technology that designed the satellite. Particularly given China's recent steps forward in world trade, industrial modernization, political reform, and revival of domestic industries, the malfunctioning of its TV-broadcast satellite is both embarrassing and surprising. In a country that has expanded its economy by a factor of ten since 1976, boasts a population more than four times that of the United States, and enrolls more students in higher education than anywhere else in the world, does this failure represent a mere hiccup or a more dangerous challenge to China's supremacy in science and engineering?

In my opinion, both readings are possible. Indeed, Chinese science has improved immensely over the past few years. To say that it has just changed is an understatement. In just thirty years, China has moved from the scientific ruin and isolationism of the Cultural Revolution towards a scientific industry that sees 20% annual funding growth. Research journals permeate China's scholarly community and China annually produces half of the world's engineering graduates. Several experts familiar with China's progress believes that China will overtake the United States in scientific funding within a few decades.

On the flip side, there are a number of political and economic problems hindering the progress of Chinese science, and they won't easily be resolved. The Sinosat-2 episode even seems to mirror the U.S.'s own space technology difficulties during the 1960's Apollo program, when the 'science gap' between the U.S. and Soviet Russia seemed apparent. The failure thus serves as an inkling that, despite progress elsewhere, China's science may still be lagging behind that of developed nations.

China intends to eliminate that gap. If skyrocketing research funding or the flood of science and engineering graduates doesn't convince the world, then projects such as the recently completed super-massive Three Gorges Dam or the first Chinese lunar expedition scheduled to launch this September should.

Separation of Science and State

The majority of challenges that Chinese research faces stems from overly bureaucratized governmental control. Research is not only funded by politicians with little to no background in science, but it is managed by them as well. Meanwhile, in most developed countries such as the United States, the majority of research and development is managed by corporate or academic institutions, separate from the state.

The attitudes surrounding science in China date back to an era in which Soviet influence on China's development was at its prime. Under the Soviet-inspired system, which reigned over China in the 1950's, the government made proprietary claims to nearly everything in the country – food, housing, police, fuel, factories – and dispensed goods and services in a top-to-bottom bureaucratic fashion. Hundreds of thousands of government employees managed and micromanaged every aspect of life in China. Various levels of authority were divided into manageable 'compartments' with very specific functions and duties.

The scientific system was no exception. Government officials directed research institutions such as the Chinese Academy of Sciences (C.A.S.) and compartmentalized them into easily-managed research blocks. Each block had a single research leader who reported to his department superior – and on up to the director of the C.A.S., who reported directly to Beijing. Many administrative levels separated researchers from the officers who oversaw funding appropriations. A lack of competition between research institutions removed any incentive to produce quality results.

The system might have worked well on a small scale, but on a large scale it stifled communication and collaboration. It discouraged the free flow of ideas and severely limited individual creativity. I asked Dr. H.S.P. Wong, a professor from the EE department who has been to China for research trips and scientific conferences, how science would work when communication between different fields and disciplines was discouraged. His answer was simple: "It wouldn't."

Since 1979, however, China has begun to dismantle its old Soviet-style systems. Today, very little of the economy remains under government control; local governments have greatly expanded their power; and companies are now responsible for a large part of Chinese business. Despite free-market economic reforms, though, Chinese scientific institutions remain under Soviet-style management.

At the Academy

A visit to the C.A.S. on a Friday morning last December was quite revealing. A friend of mine (to whom I will refer as Y.Q.), a student at Peking University who was working at the C.A.S. part-time on some semiconductor physics research, invited me on a brief tour of the facility. The C.A.S. is a gated and guarded compound set within Beijing Forestry University featuring several Institutes housed in various (rather large) buildings. The building in which Y.Q. works, the Institute for Electronics Research, is a featureless gray box sitting beside similar gray boxes housing other C.A.S. subdivisions.

It was a cold morning (which, as I learned the hard way, is typical for Beijing in December), and though it was late in the morning, hardly anybody was around. At first, I was eager to get out of the freezing air, but the interior of the building was hardly any warmer than outside. I asked Y.Q. why the halls were not heated.

"Why do they need to be?" Y.Q. answered. "The offices and labs are heated, so everyone just stays there."

This explained why the thin and featureless hall was as empty as the compound's courtyard. Walking down the hall, I only saw scientists on their way out the door to smoke. Each door I passed declared the name of a department: 'Institute for Magnetics Research', 'Institute of Thermionics Research', 'Institute of Semiconductor Research.' I began to see the influence of the Soviet system: it seemed that the departments were divided from each other not just on administrative lines, but also physically by office location. All of the doors that I passed were closed to keep the warm air inside.

Y.Q. had explained some of his research to me before, and I was interested in seeing where he performed his experiments. He had started researching at the C.A.S. because one of his professors at Peking University had put him in contact with a lab leader in the Institute for Semiconductor Research. For about a year, he had been pursuing spintronics work there, and he had recently started doing research with another professor in the department. As we neared the door marked "Institute of Semiconductor Research," he turned toward me and said, "I wanted to mention, please don't talk about my work in the other lab."

"Why?"

"This professor and the other professor are competitors, so I'd rather he not know that I'm working in another group."

"You mean, these professors have bad guanxi?" (Bad guanxi means that two people don't get along well at all.)

"Yes, if one of them finds out…" Y.Q. struggled to find the right words, but his meaning was obvious. I was curious, though, as to why these two professors couldn't tolerate an undergraduate working in both groups. The answer was somewhat surprising:

"Their work is very similar … one of them works on semiconductor photonics, and the other works on spintronics. They have bad guanxi because they think the other guy is going to steal their work."

Y.Q. went on to describe a number of "inconveniences" he had to deal with on a daily basis. He had to pretend not to know things he had discovered in the other lab group, because otherwise his lab leader would become suspicious that he was working outside the lab group. He could not use pieces of equipment from both labs at the same time, because the departments would not allow the sharing of tools. He could not ask some of the lab members for help, because he would not be allowed to cite their assistance in his technical paper. I found the situation a bit ironic; was not the C.A.S. supposed to represent the most visible and transparent scientific community in China?

There is no paucity of brilliant scientists in the Chinese Academy of Sciences. The project posters I saw on the walls inside the labs described cutting-edge projects in atomic force microscopy, fluid mechanics, ion implanting, and optoelectronics. But the outdated system, with its restrictions on connections and community, makes the flow of ideas between departments very difficult. Scientists are encouraged, if not forced, to stay within their groups and avoid cooperation with other departments – especially if those departments are engaging in similar research projects. Between the administrative walls and the cold hallways separating the offices from each other, work in C.A.S. is quite solitary.

Change from Inside or Outside?

Based on what I heard from several researchers during the visit, change within the C.A.S. is unlikely. The Academy is too well-established to change, even though bureaucratic organization clearly retards the creativity and innovation of research. Furthermore, the guaranteed government funding gives C.A.S. and other Chinese government-run science institutions little incentive to become more efficient and effective.

Although the Chinese Academy of Sciences is unlikely to lead an institutional revolution, Chinese universities and corporation are beginning to change the way research and development is done in China. China is moving toward a U.S.-like model in which most research institutions are not government-owned (though they may be supported by government funding). From the perspective of scientific progress, the system works pretty well: the transistor, the personal computer, and the internet (among many others) were all invented in corporate and academic settings. The shift from state-run to private-run research has been picking up speed in recent years and will certainly continue in the near future.

In the United States, corporate research dwarfed academic science up until the 1990's. Most of these companies have been foreign multinational firms, like Microsoft and Intel, looking for a large supply of engineers to fill technical roles. These companies continue to expand their operations within China – Microsoft announced a plan last November to focus its venture capital toward Chinese technology startups, and Intel has begun to set up offices throughout the country. The rising domestic market has made room for national industries to grow, which in turn will create the competition within China needed to fuel scientific progress.

Despite the role of these companies within Chinese technology, the most interesting change has taken place in the academic world. Chinese universities have truly blossomed into world-class institutions. While the elite universities – Peking, Tsinghua, Fudan, etc. – are state universities, corporate partnerships have provided the additional resources needed to further the quality of various departments. Tsinghua's electronics department, for example, has partnerships with IBM, Texas Instruments, and Intel. Along with the additional resources afforded toward Chinese universities comes a different perspective on scientific research, one primarily based on the U.S. model.

How Soon?

This is where the speed of China's modernization comes in. The fast-paced economic upturn of the last quarter-century has fostered an environment for changes occurring at breakneck pace. At Peking University, I visited Professor Lianmao Peng, a member of the Electronics Department who is one of China's leading academic authorities on nanotechnology. His office is located in a gigantic gray-and-white five-story building, and his group works in two labs in the basement. After giving me a tour of the labs – which have rather state-of-the-art machinery, including transmission and scanning electron microsopes and an atomic force microscope – I realized that he hadn't shown me a cleanroom. He said, "No, but we're planning on building one." He then showed me a patio in the building's central courtyard where they were planning to build a new fabrication lab.

"How big is it going to be?" I asked.

"This entire square," he responded. I looked at the area and estimated that it must be around 1000 square feet, at least. While it is true that the area was not particularly breathtaking – the Stanford Nanofabrication Facility cleanroom has over 10,000 square feet – I was impressed by the near impossibility of getting equipment to the location. The Electronics Department building surrounded the courtyard on all sides; getting machinery into the area would be a nightmare. I considered all this for a minute and estimated the shortest possible construction period:

"How long will it be until the facility is ready? About a year?"

"No, no, not nearly that long. Six months at most." I thought, are you kidding me? In addition to being surrounded on all sides, the area was covered in rubbish and would likely need to be bulldozed before construction. But Professor Peng was absolutely serious – six months, tops.

China's Greatest Asset: Its Students

The Chinese university system's greatest assets are its students. Universities have been encouraging individual thought and creativity more than in the past, and the results are starting to show. Moreover, universities are actively hiring professors who have spent part of their lives outside of China experiencing systems that work much differently – such as Professor Peng, who received his Ph.D from Arizona State University. These professors have instilled in their students a vision of how the system could transform.

The largest ongoing change in Chinese science, though, is the movement of Chinese students themselves around the world. In previous decades, this was not possible, at least not on the scale that it is happening today. Rising incomes in China have allowed students to travel across borders. Most of these students travel to nearby countries (Y.Q. himself spent a semester researching at Tsinghua National University in Taiwan), but they also end up all over the world. China is now trying to attract many of these scholars back to their home country, and many are returning, either out of sense of opportunity or sense of home. These world-traveled graduates will take a major part in transforming Chinese science over the next several decades and, eventually, in narrowing discrepancies between China's growth as a whole and the growth of its science.

Conclusion

Reform in China's research institutions are necessary for China to become not only successful but also respected. At one point during my stay in China, I was reading and the domestic-made lamp I had bought there suddenly stopped working. After inspecting it, I discovered that the power transistor had burnt up. The lamp had been poorly designed, or at least poorly manufactured, and while I placed it in the trash bin I realized I felt a little less hopeful about China's future than before. And every once in a while, an episode like Sinosat-2's failure leads us to question China's scientific progress. But don't be fooled. Regardless of the setbacks and humiliations, China is knocking at the door of the world's scientific community.

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A Taste of Bioengineering

Where Bio meets EE

By Spencer Chu

Introduction to Bioengineering

Electrical Engineering is arguably one of the most diverse majors offered at Stanford. As one of the few majors that require further specialization in a specific track within the discipline, EE encompasses a wide array of different topics. Whether learning about signals processing to analog circuits to digital hardware, the EE major can easily immerse himself in a subset of the diverse fields and research conducted by the department. Yet, despite their breadth, researchers in the department sometimes are not able to tackle the increasingly-complex challenges of modern day technical challenges on their own. As a result, researchers in Electrical Engineering frequently find themselves collaborating with fellow researchers from other departments. These "interdisciplinary" fields of research are at the forefront of many of today's most challenging and rewarding breakthroughs.

One such interdisciplinary field is bioengineering. As a field that connects the technical empowerment of electrical engineering with the physiological knowledge of biology, bioengineering seeks to produce practical applications that can supplement biological systems, from synthetic limbs to nervous systems. Here at Stanford, bioengineering as a formal discipline is in its nascent stages. In 2002, Stanford established the Department of Bioengineering conferring only graduate level degrees. At the undergraduate level, the department has no established curriculum or degree, although there are bioengineering-related tracks as addenda to other majors.

Professor Krishna Shenoy and Bioengineering

Despite the relative academic youth of bioengineering here at Stanford, bioengineering research has a long history. In the past decades, students and professors from the Electrical Engineering, Mechanical Engineering, and Biology departments – to name a few – have applied their academic expertise to bioengineering issues. Professor Shenoy from EE is one such member of the collaborative research community.

Professor Shenoy began his undergraduate career in a bioengineering track at the UC Irvine. However, Shenoy left the "jack-of-all-trades, master-of-none" type education offered by bioengineering in favor of the rigor and depth offered by electrical engineering for one of his other passions: computation. Shenoy graduated with a B.S. degree in 1991 and continued his studies at MIT, culminating in a Ph.D. in 1995. With a strong electrical engineering foundation, Shenoy formally revisited his passion for bioengineering by serving as a postdoctoral fellow at Caltech's Division of Biology from 1995-2001. In 2001, Shenoy joined Stanford's Electrical Engineering department, where he currently heads the Neural Prosthetics System Laboratory.

The Language of Bioengineering

For Professor Shenoy, understanding biological systems was as crucial as understanding electrical engineering in laying his foundations to conduct research in bioengineering. In his interpretation, both electrical engineering and biology have their own respective "languages" – ways of thinking, pools of knowledge, methods of attack. Often, when researchers with different backgrounds tackle an emerging field such as bioengineering, they get "lost in translation." While information is available, the language to access that knowledge is not – bioengineering requires not only a synthesis of skill sets from diverse group of researchers, but also its own language to address the unique set of challenges posed by this amalgam of paradigms from biology and engineering.

For Shenoy, developing that language was a two-part process. First, he established a strong foundation in electrical engineering in his undergraduate and graduate studies. Second, he bridged over to biology during his post doctorate studies. Finally fluent in both languages, Shenoy then assimilated the two, empowering him with the understanding and toolset to handle bio-

engineering issues.

The Brain and the Letter

Despite receiving separate rigorous training in both electrical engineering and biology, Professor Shenoy does not favor the methodology of one discipline over the other. Instead, he sees the nuances of each discipline as tools, from which the researcher may select the best fit for a particular task.

Consider one of Professor Shenoy's current projects. In order to help completely paralyzed patients to use computers, Professor Shenoy is developing an interface that directly connects a patient's brain to a computer.

At the beginning, the project was focused around the interface, and naturally Professor Shenoy adopted a more traditional electrical engineering approach, one fundamentally based on design. The interface would first have to detect minute brain signals; second, it would have to amplify signals to a more reasonable range of operation; third, it would have to interpret signals as specific actions; lastly, the entire interface would require low power consumption to ensure longevity and low heat dissipation. When phrased in this particular way, many of the biological aspects of the problem translate into design parameters: For instance, small brain signals require sensitive detectors, implanting a chip in the brain requires 'neutral' materials that will not agitate the immune system, and low power consumption is required to ensure brain tissue is not heat-damaged.

The system constructed by Shenoy et al. was successful; paralyzed patients could type with their minds. However, the system quickly ran into performance barriers: if patients thought about too many letters too quickly, the interface would fail. Professor Shenoy isolated the problem within the interface's interpretation techniques. In order to adjust the algorithm, Professor Shenoy had to better understand exactly how the brain processes thought about letters. In contrast with the earlier design problem, this type of issue naturally fits with the hypothesis testing approach of biology. After conducting additional research, Professor Shenoy determined that as the rate at which people can think about different letters increases, the brain signals fundamentally change. This phenomenon is analogous to speech: as a calmly delivered speech is sped up, the once concisely delivered words gradually become slurred, fundamentally changing their sound. Armed with this new biological information, Professor Shenoy increased the speed barrier from roughly 4 words/minute to 15 words/minute.

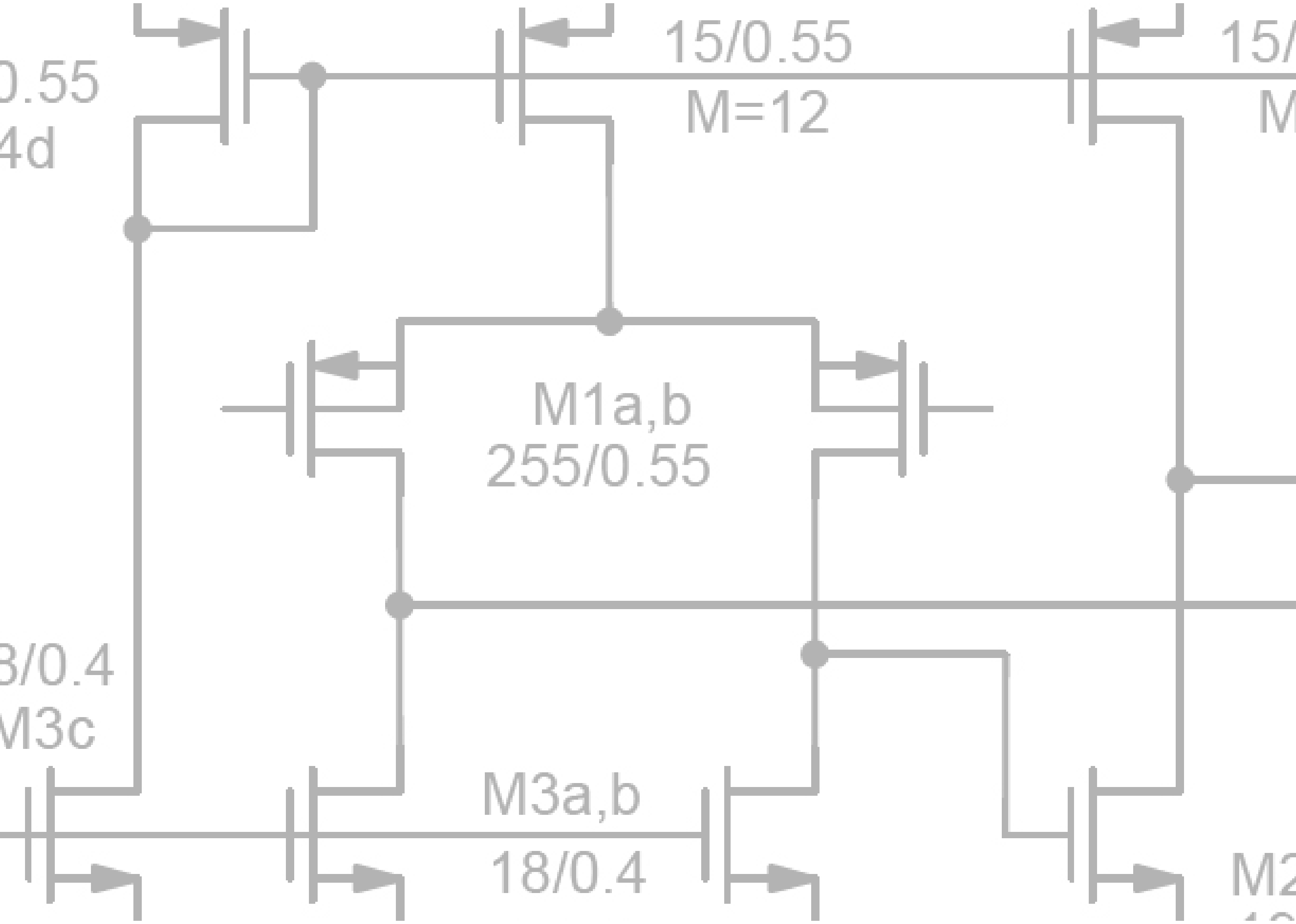
Interdisciplinary Interactions

This particular research project highlights one of the most important points of interdisciplinary research: the harmony between both sub-disciplines. For examples, bioengineering is not just applying engineering to biology or vice-versa. The two disciplines, in a sense, support and propel the other. For instance, the creation of this brain-computer interface demonstrated incompleteness in our understanding of the brain. Moreover, a better understanding of the brain allowed the creation of a more effective interface. Continuing to push the limits of the interface, the cycle repeats itself as further improvements to the interface will require additional information about the brain. Engineering is not merely augmenting biology, and biology is not merely supporting engineering; both disciplines work in unison, and as a result, paralyzed patients now have the remarkable opportunity to type on computers.

Future Studies

Engineering and biology both have much to gain from bioengineering research. With electronic systems, biology now has a means to augment parts of the human anatomy that previously had been untouched. From prosthetic limbs, to pacemakers, to brain-computer interfaces like Professor Shenoy's, the potential to improve upon human health is simply staggering. Likewise, engineering has just as much to gain. As many of our electronic devices mimic the biological systems around us, a stronger understanding will lead to better designs for information control systems. Bioengineering is just one of many promising disciplinary fields. As new fields become established traditions, the definition of interdisciplinary will change. New challenges will arise; new boundaries will be pushed. The excitement of research today is only a taste of the future.

Spencer Chu is a Junior in Electrical Engineering.



The Integrated Circuits Laboratory

A Historical Overview

BY VINCENT MEI

As one of five main research laboratories that constitute Stanford University's Electrical Engineering Department, the Integrated Circuits Laboratory has a long and rich history dating back to the beginning of solid state research at Stanford. The laboratory consists of 14 faculty members, 9 research associates, over 100 Ph.D. students and 10 full-time staff members with research agenda encompassing both system and devices.

Founding of the Integrated Circuits Laboratory

[While this article is not an exhaustive account of the history of the Integrated Circuits Laboratory at Stanford University, it strives to provide an accurate description of the people and motivations behind its inception.]

Following World War II, the vacuum tube dominated the field of electronics. With the invention of solid state transistors, a new age of research into circuits and devices began. Realizing the future of electronics was in solid state, Frederick Terman – the dean of the School of Engineering at Stanford University then – was quick to hire John Linvill. Having performed his doctorate studies at MIT and worked at Bell Labs, Linvill was sought by Terman to be "the person we need to transistorize our electrical engineering curriculum."

After Linvill's appointment in 1954, James Gibbons joined Linvill as a Ph.D. student developing and studying semiconductor device fabrication. Gibbons' work was so impressive that he joined the faculty of Stanford's Electrical Engineering department only one year after graduating from Stanford with his Ph.D. in 1956. While at Stanford, Linvill realized that Stanford's Electrical Engineering graduate students needed "hands-on" experience building and designing their own semiconductor devices. This essential engineering insight is what Professor James Gibbons describes as "[building] what you want to study," and would go on to guide the Electrical Engineering department's vision for the last four decades. Under the guidance of Linvill and William Shockley, Gibbons established the solid state electronics laboratory, a precursor to ICL, within a year.

For a short while, Professor Linvill was a member of the solid state electronics laboratory. Later, his ambitions to extend his research focus on integrated circuits technology and processes led him and his colleague Professor John Moll, a former professor of Electrical Engineering at Stanford and employee at Bell Labs, to found the Integrated Circuits Laboratory.

In 1967, Linvill and Gibbons hired James Meindl a recent graduate of Carnegie Melon University. Meindl's hiring to the Stanford Electrical Engineering Faculty represented the department's shift towards a more system level focus in integrated circuits. While at Stanford, Meindl served an integral role in establishing ICL, acting as the founding director of both ICL and the Paul G. Allen Center for Integrated Systems. Under the direction of Meindl, Linvill, and Gibbons, the Integrated Circuits Laboratory was geared to have a high intensity focus on semiconductor design and processes in integrated circuits.

Beginning in the early 1970s, Meindl helped hire the current generation of Electrical Engineering professors in the Integrated Circuits Laboratory, including Professor Robert Dutton, Professor James Plummer, Professor Bruce Wooley, and Professor Krishna Saraswat. The hiring of these professors further strengthened the department and research in ICL, and brought us to the present success of ICL and its current location, the Paul G. Allen Center

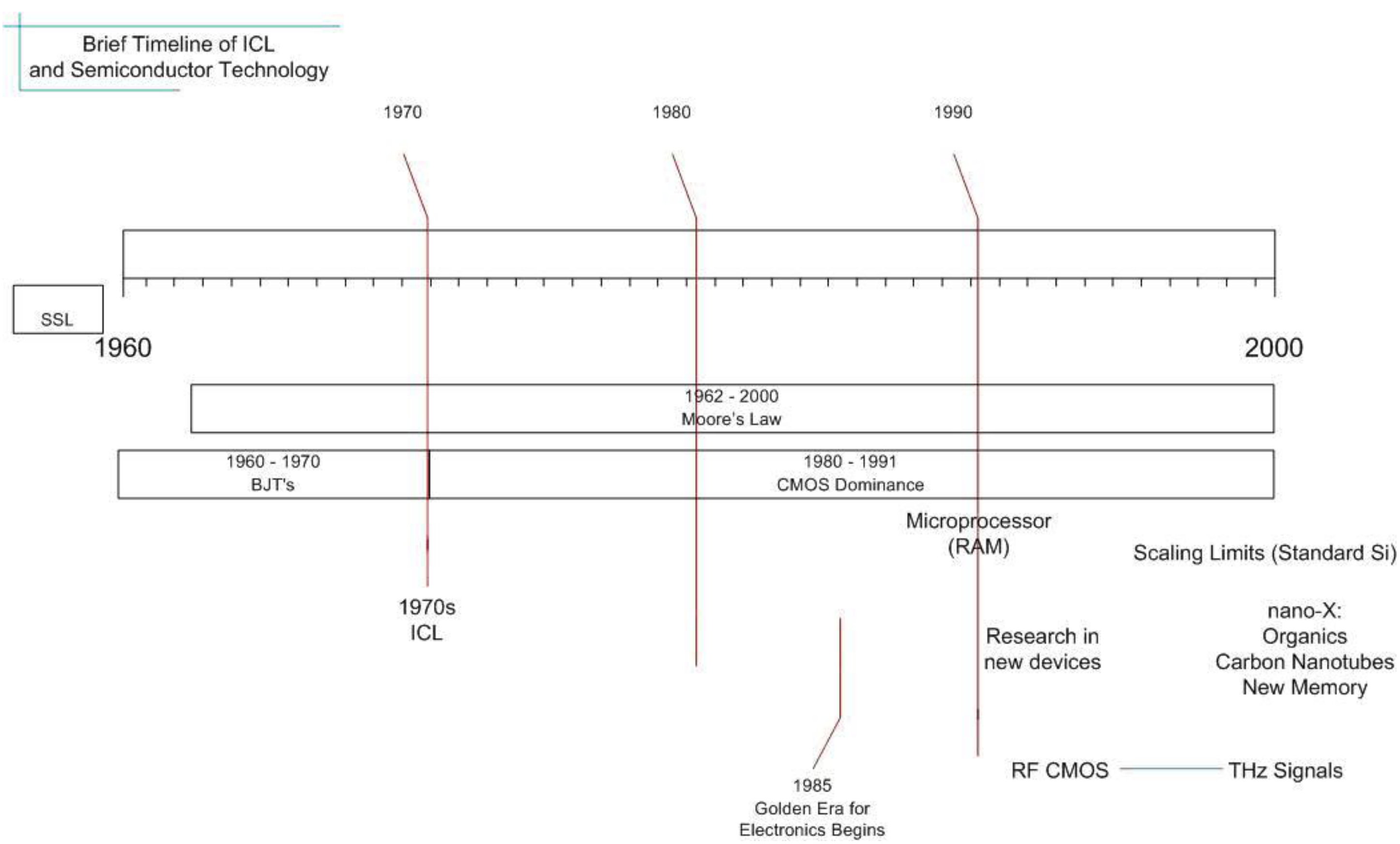


Figure: Brief Timeline of ICL and Semiconductor Technology

for Integrated Systems.

ICL's Home: The Paul G. Allen Center for Integrated Systems

Within thirty years of John Linvill's appointment to Stanford Electrical Engineering's faculty, the Center for Integrated Systems, the current home of ICL, was established. Beginning with Frederick Terman's vision to stay at the leading edge of electrical engineering in the early 1950's, the Center for Integrated Systems was established to bring together academia and industry to further advance and study circuits and processes. Rather than following a more traditional model of university research later developing into corporate research, CIS was a revolutionary mixing of academia and industry allowing a real-time, two-way transfer of knowledge between academia and industry.

At its inception in 1983, under James Meindl and John Linvill's guidance, CIS was sponsored by fifteen partner companies including Digital Equipment, Fairchild Semiconductors, General Electric, General Telephone and Electronics, Hewlett-Packard, Honeywell, IBM, International Telephone and Telegraph, Intel, Motorola, Northrop, Tektronix, Texas Instruments, TRW Inc., and Xerox. Each company paid a $750,000 fee over a three year period to participate in the research collaboration. In addition to this corporate funding, CIS also received eight million dollars from a contract with the Department of Defense. The initial capital generated from fees and contracts, funded the construction of the central laboratory of CIS, the current home of the Stanford Nanofabrication Facilities.

Currently, CIS maintains corporate partnerships with twenty-three companies throughout the semiconductor and related industries. By entering into a partnership with CIS, the member companies gain access not only to a wide range of research opportunities and equipment that are of interest to the company, but also to the wealth of knowledge within the Stanford community.

CIS is also home to the Stanford Nanofabrication Facility, a member of the National Nanotechnology Infrastructure Network, a National Science Foundation funded organization of universities participating in nanotechnology research. Through teaming graduate students, professors and industry in research, CIS develops the fundamental knowledge base and design structure necessary to create electronic systems at a global level. The range of research topics covered by the faculty in CIS covers research both into circuits and at the system and device level.

Interviews with Professors

To gain a better perspective on ICL and its operations I sat down with Professors Boris Murmann and Yoshio Nishi in an informal interview. In this interview, we discussed various topics ranging from motivations for research to where ICL is headed in the future. Below is background on each professor and a short description of their research interests:

Professor Boris Murmann
Head of Mixed-Signal Integrated Circuits Design Group

After receiving a Ph.D. from Berkeley in Electrical Engineering and working in industry, Professor Boris Murmann came to Stanford to head the Mixed-Signal Group. Murmann's Mixed-Signal Integrated Circuit Design Group is primarily concerned with mixed-signal circuit design. Currently his group is working on mixed signal circuit design. They also work on improving the design, sensitivity, and power consumption of sensor interfaces. For more information please visit: http://www.stanford.edu/group/murmann_group/index.html

Interview with Professor Simon Wong

Background

Professor Simon Wong joined the Electrical Engineering Department in 1988 and concentrates on solving problems associated with high-speed integrated circuits. His research projects primarily concentrate on how to overcome the limiting factors in modern integrated circuits such as interconnections and packages. More information relating to Professor Wong's research is found at his group's website: http://marco.stanford.edu/swong/research.html.

Interview with Professor Simon Wong

Professor Wong: First, let me explain the EE Lab structure. The EE Dept has a very large number of professors covering a wide spectrum of interests and occupying multiple buildings. The Lab structure is merely a method to organize the professors. The professors in each Lab are interested in a similar area of research and hence are located in the same proximity to enhance collaborations. However, it is common to find research collaborations across Labs, departments, even universities and industry. For example, I am leading a research program in 3-Dimensional Integrated Circuits that involves 6 professors from ICL, 1 from ISL, 1 from CSL, 1 from Materials Science, 2 from Chemistry, 1 from Princeton University, and 1 from Hewlett Packard. Hence, the boundaries between Labs are somewhat fuzzy and dynamic. Occasionally, the Labs are re-structured to better meet the teaching needs and research opportunities. For example, in 1997, the then Solid State Lab was split. Some professors joined ICL, some joined then Ginzton Lab to form the Solid State and Photonics Lab.

ECJ: How long have you been with ICL?
Professor Wong: When a professor joins the EE Department, he/she can choose to be affiliated with any Lab or multiple Labs. When I joined Stanford in 1988, I chose ICL because my research interests closely aligned with those of many professors in ICL.

ECJ: Could you provide an overview of your time at ICL?
Professor Wong: ICL has a long and productive history that tracks the tremendous growth of the semiconductor industry. There are many examples of our research results making an impact and helping the industry to move into a new direction. ICL also manages the Stanford Nanofabrication Facility, one of the largest university semiconductor research facilities in the USA.

The research in ICL has evolved and grown over the years. We have focused on helping the semiconductor industry to extend silicon based technology, devices and design. In addition, we have applied the vast experience into new areas. These include micro-electro-mechanical systems (MEMS), bio-MEMS, bio-electronics.

The basic device and technology that have powered the explosive growth of the semiconductor industry are expected to run into serve limitations within the next decade. Fundamental changes in device, materials and design methodology are imminent. We see this as a great research opportunity for ICL. Furthermore, we see tremendous opportunities too.

ECJ: Could you describe your research and what your group is working on?
Professor Wong: I am mostly interested in research that will eventually become a practice in the industry. I have found ICL offers the most appropriate environment for my research needs and professional growth, as well as plenty of collaboration opportunities. My own research has evolved over the years. When I first joined Stanford, I was mostly interested in the technologies for fabricating integrated circuits. At that time, the technology for interconnecting transistors was based on aluminum alloy, and was facing performance and reliability limitations. I chose to explore an alternative material, copper, of which the industry was very skeptical then. I remember that a research sponsor jokingly told me to keep our wafers with copper film at Stanford for fear of potential contaminations. Eventually, the industry learned and adopted copper in routine manufacturing.

Later, I became interested in integrated circuits for radio frequency (RF) applications. At that time, all RF integrated circuits were manufactured with compound semiconductor or silicon bipolar junction transistors (BJT). Silicon MOSFET was deemed inferior for above GHz operations. My students focused on solving various modeling and design issues of silicon RF-IC. Nowadays, silicon MOSFET is the dominant RF technology for WLAN, Bluetooth, GPS applications, and is slowly migrating into mobile phones. Currently, my group is exploring silicon technology for microwave, above 50 GHz, applications. We are also looking into new non-volatile technology, especially for 3D integration. The dominant non-volatile memory technology that enables flash drive, MP3 player, digital camera is expected to face sever limitations in the next 5 to 10 years. My experience has been that whenever the industry is running into a roadblock, it is an excellent opportunity for the university to explore new ideas that may eventually change the course of the industry.

ECJ: Would you draw a diagram of your research group within the framework of ICL?
Professor Wong: ICL is not like an industrial company with a structured organization. ICL is a dynamic organization with ever changing and diversifying directions. We do not want a framework that may limit our creativity. We are always searching for new and exciting opportunities.

ECJ: What would you recommend to undergraduates interested in research in circuits do to get involved? What courses to take and when?
Professor Wong: Circuit design is the art of connecting devices to deliver useful applications. Hence, a superior circuit designer must understand the physics and operations of the device, the limitations of the model, and the system in which the design will eventually go into. Furthermore, the designer must be aware of the upcoming changes in device structures or system applications and how these changes may affect the circuit architecture or design methodology. Hence, in addition to circuit courses, students should diversify their learning to include device physics, and selected system knowledge (e.g., signal processing, communications, or computing) depending on which application area the student would like to focus on.

ECJ: What essential characteristic makes a good researcher?
Professor Wong: I can only speak about my experience in semiconductor research. In the research areas that ICL is involved in, industry is our best supporter but can also turn into our worst competitor. There is a fine line between performing industry relevant research and being rolled over by the industry. It is very difficult to compete directly with the industry due to our limited human and financial resources. This line continues to advance towards us: successful university research is quickly turned into industry development. One must stay abreast of the industry practices and trends, keep learning new knowledge to stay ahead of the industry, and work swiftly when the research opportunity or idea appears. I guess if you can do all these, you can be successful in any career.

Professor Yoshio Nishi
Director of Stanford Nanofabrication Laboratory

As the director of SNF, Professor Yoshio Nishi successfully won a competition to gain funding for SNF in 2003 between Berkeley, Princeton, and MIT allowing Stanford and Cornell University to become the two major research sites of the NNIN. This attracted many companies to Stanford who use its capabilities to verify and test their product at SNF. Professor Nishi's research serves as an example of how ICL is expanding its research breadth. His Nano-Electronics Group is currently developing and exploring nanoelectronics from a process and device perspective. Because of the multitude of disciplines required, the group is affiliated with multiple departments and contains students from various science and engineering majors. A combination of researchers from the Electrical, Chemical, Mechanical, Materials Science Engineering departments currently staff the Initiative for Nanoscale Materials and Processes, which is concerned with understanding the fundamentals of metal gate, high K diaelectrics, high mobility channels, and explore extensions beyond 20nm. Professor Nishi's group is also investigating nonvolatile memory technologies which will allow for ultra high density memory, cleaning technology for germanium semiconductor technologies, III-V semiconductors, and nanotube/nanowire research. For a more complete list of Professor Nishi's research topics and descriptions please visit: http://nanodevice.stanford.edu/research.html.

For Professor Nishi, the most interesting part of ICL and what drew him to a career in research was, as he described, "the era in new discovery" in Electrical Engineering. He realized that the discipline is broadening to include topics such as materials science, chemistry, physics, and recently medicine with exciting new applications.

When I asked, "Why did you become a professor?" both Professor Nishi and Professor Murmann agreed that the challenges presented by research and the freedom for exploration were the greatest rewards of becoming a professor. In particular, Stanford allows for a great mix of academics and industry, providing varied opinions and views essential for discovery and learning. Professor Murmann especially appreciates that a career in academia continually presents new and interesting challenges while providing the chance to interact and cooperatively work with many different types of people. Professor Murmann finds research much more rewarding than private sector work because it allows one to work for the sake of learning and discovery.

For students interested in research, Professor Nishi acknowledges the importance of having a strong sense of curiosity and intense focus. While Professor Murmann also emphasizes the importance of having intense focus, he acknowledges that true research stems not from hand-holding but from following one's instinct. As he described in our interview: "There is no recipe for following instinct, there are no easy ideas to obtain, every contribution is very hard, and the researcher must be extremely self-driven. Good research does not happen through hand-holding."

Both professors acknowledged the growing importance of cross-disciplinary work in the future of ICL. More and more, Electrical Engineering and other departments are collaborating to develop new technologies. As Professor Nishi described, professors from a multitude of departments including, Materials Science, Chemistry, and Physics to name a few, are working with him in the Initiative for Nanoscale Materials and Processes a program specializing in developing nanotechnology and its fabrication processes.

Interview with Professor Robert Dutton

Background

Professor Robert Dutton, the current director of the Center for Integrated Systems, heads the Technology Computer Aided Design group, which studies TCAD software and how to model new device technologies. The group is also credited with developing SUPREM and PISCES, which have spawned later industry versions. Currently, Professor Dutton's TCAD group is studying mixed-signal noise coupling, nano-scaled devices, simulation and design of optical interconnection structures, radio frequency (RF) devices including noise limitations and various reliability issues associated with electrostatic discharge, thermal modeling, and substrate noise. For more information please visit: http://www-tcad.stanford.edu/

Interview with Professor Robert Dutton

ECJ: How long have you been with ICL?
Professor Dutton: Very interesting story, it dates to William Shockley and the early days of the Solid State Lab (SSL) which is mid-1960s (roughly). John Linvill, Jim Meindl and Jim Angel were the founders as a "spin off" of SSL.

ECJ: Could you give me an overview of your time at ICL?
Professor Dutton: Again, a rather long story. I joined in 1971 in order to start a CAD group. This was during the early days of Moore's Law and I established a Technology CAD program (paralleling UC Berkeley's SPICE work) to develop simulators to follow Moore's Law of transistor scaling.

ECJ: What do you find most interesting at ICL?
Professor Dutton: Circuits are the ubiquitous vehicle to "make things happen" in electronics. This is the "behind the scenes" miracle of making electronics work of everything, everywhere and in a non-stop way.

ECJ: What do you find most interesting in your research? Why did you choose to go down this path?
Professor Dutton: CAD allows things to happen more efficiently and helps to overcome limits of the human mind to digest details. We started with SPICE (for circuits) and my research developed TCAD which details with ALL the details of the complexity of IC processing and device design. Why did I go this way? Well, it was needed and no one had done what our group was able to create.

ECJ: Could you describe your research and what your group is working on?
Professor Dutton: Well, let me attach as summary of some of the cool stuff. We are now looking at TCAD for: RF circuits; ESD protection; interface electronics (ADC, SiP etc.), Opto-Electronic (OE) circuits etc. Basically, a whole bunch of analog-oriented issues in the space called "System on Chip" (SoC) as well as "System-in-Package" (SiP).

ECJ: What are some new directions in ICL research over the past decade? How has ICL changed?
Professor Dutton: Changes include—Organic materials (Peumans); Bio-Electronics (Shenoy); Digitally-enhanced analog (Murmann); MEMS ((Howe); nano-electronics (Philip Wong). Basically, new (young) faculty have changed ICL in a MAJOR way!

ECJ: What are the greatest challenges in performing and presenting your work?
Professor Dutton: Money, Money, MONEY! The government is sort of bogged down in paying for things like the war, health care etc. (NOT spending enough on R&D). Getting towards the "end of Moore's Law" is a challenge. New themes such as "nano" and "bio" are drawing the new funds. Ongoing "evolution" of electronics doesn't seem as high profile and worthy of funding as it was a decade ago.

ECJ: From a CS/non-EE perspective ICL is just circuit research. What else do you find interesting about research at ICL?
Professor Dutton: A good question. Simple answer… the world is ANALOG! How to interface with all the information that is in the "real world" requires a broad view of "interfaces" and dealing with data and problems wherever they are… bio, environment etc. There is a HUGE world out there with real problems to address. The ICL is ready to tackle the hard problems of getting data, processing it and giving real solutions (electronics that help you really DO SOMETHING!).

ECJ: What do you find most challenging about research at ICL?
Professor Dutton: Finding the right problems to work on and having students that are up to the challenge of making real progress ON THEIR OWN (versus wanting a "pre-defined" problem set to work on).

ECJ: What is the future of your group, where do you see it headed?
Professor Dutton: I'm headed for retirement pretty soon. I only take on "the best and brightest" who have the drive as well as the resources (financial aid) to do research. I am happy to keep looking at new challenges in the "post-Moore's Law" era—and there are MANY challenges. However, I am purposefully NOT setting an aggressive 'research agenda.'

ECJ: Is there any interaction between different groups within ICL?
Professor Dutton: This is a WONDERFUL aspect of both Stanford and our ICL faculty. We LOVE to work together and leverage from our different backgrounds and expertise. Many examples to discuss: Meng-Shenoy; Wong-Peumans-Howe; Wooley-Murmann-Dutton…etc.

ECJ: What would you recommend to undergraduates interested in research in circuits do to get involved? What courses to take and when?
Professor Dutton: Courses is just to get the background…(Core + 100-level "depth" courses…116, 114 etc). You need to get to know the faculty, get engaged in discussions (join group meetings) and show that you are ready to: 1) talk to the grad students and 2) think "outside the box" in terms of a) reading the literature and b) trying things without waiting for someone to 'give you a problem set.'

ECJ: What essential characteristics make a good researcher?
Professor Dutton: Curiosity and drive…not waiting for someone else to tell you what to do.

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research

A Novel Optical Fiber Bundle Proximity Sensor

By Michael Fischer

In this paper, we describe our research in the design and construction of a novel optical fiber proximity and touch sensor. The principle idea is to construct a proximity sensor using a bundle of optical fiber pairs. In each pair, light is transmitted through one optical fiber onto the target object and the reflected light is then transmitted back through the second optical fiber. The bundle of optical fiber with the reflected light is then fed into a camera. Software is used to filter and measure the amount of reflected light in order to determine the distance to the boundary of the target object. Using this information, the shape of the object can be determined. Potential applications of this model sensor are also discussed below.

Introduction

The ability to detect an object before physical contact allows humans to better sense and interact with obstacles in their surrounding. Humans make extensive use of proximity sensing in order to determine many of the characteristics of an object, such as its shape and location. Similarly, a robot equipped with proximity sensors would be well-adapted to locate and manipulate objects in its environment.

Proximity sensors are extremely useful in a variety of applications. One specific application is a robotic finger, as shown in Figures 1 and 2. When the optical fiber proximity sensor is installed on the finger, it allows the robot to anticipate the location of the target object well before contact with it. Additionally, the optical fiber proximity sensor is able to identify the shape of the target object without touching the object. This is extremely useful because it allows the robot to move quickly in a large area, detect obstacles, and decelerate appropriately to avoid collisions or to make proper physical contact. Furthermore, the robotic finger is able to determine the contours of a target object so that it can prepare for an effective method of grasping the object.

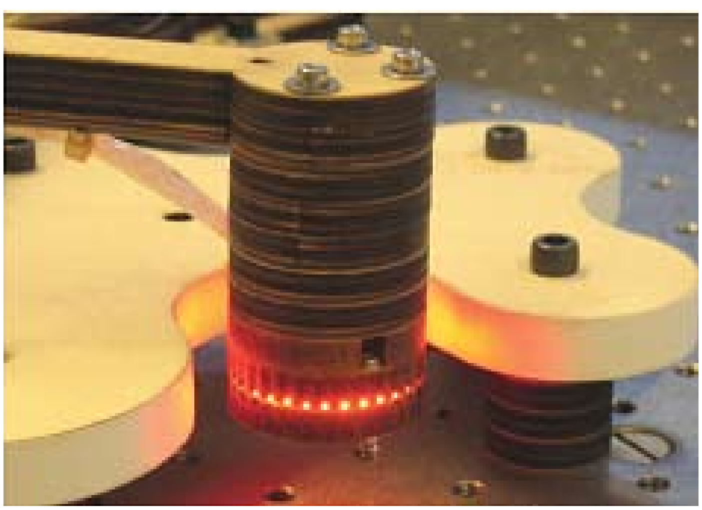

Figure 1. The constructed optical fiber proximity sensing "finger" used on the robot.

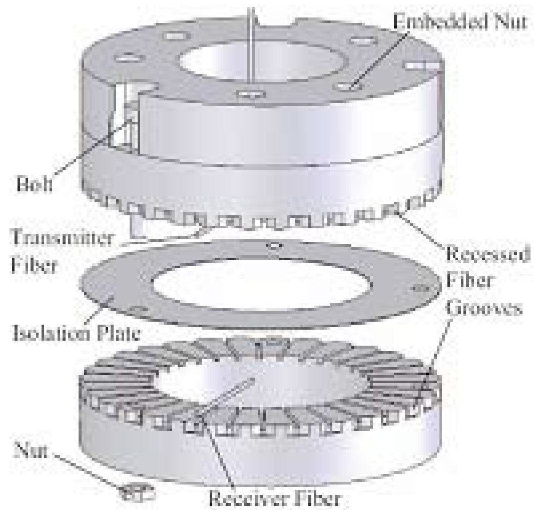

Figure 2. Expanded view of the sensor. The top and bottom pieces were made from plywood using a LaserCAMM rapid prototyping machine. Transmitting optical fibers are placed in the groves on the top piece. Receiving optical fibers are placed in the groves on the bottom piece. There is an isolation plate between the two fibers to prevent stray light leaking from on fiber to the other. The entire assembly is bolted together.

Prior Work and Existing Sensory Systems

Proximity sensing has been used and researched extensively in the field of robotic navigation[1,2]. However, there has been little research in determining how proximity sensing can be used for grasping and manipulation of objects.

In the field of robotic navigation, robots are often equipped with laser range finders or sonar sensors which are used to map out surrounding areas in order to avoid collisions with other obstacles[3]. A robot may also be equipped with a sensor consisting of an LED and photo-resistor pair mounted on its anterior surface so that when the robot is near an object, the light from the LED is reflected from the object and subsequently detected by the photodetector. Using this technique, robots are able to detect objects to avoid collisions. However, such techniques are inadequate to map out the contours of objects in the surroundings.

Optical Fiber Proximity Sensor Implementation

A complete optical fiber proximity sensory system is composed of many individual optical fiber pairs assembled in a bundle. In each functional pair, one optical fiber strand transmits light from a source onto the target body. The second optical fiber strand then collects the reflected light from the target body and transmits this light to a camera where the signal is interpreted, as shown in Figures 3 and 4.

The light is emitted from a central red 3W Luxeon LED unit. Light from this LED is projected onto one end of the optical fiber and transmitted to the tip of the sensor where it is emitted onto the target object. A web camera was used to create a device that could measure the intensity of the light reflected back through the receiving optical fiber strands.

One novel aspect of this research is its use of optical fibers to create a high-resolution two-dimensional map of the object. Optical fibers allow the beam of an LED to be focused and more effectively target an object. Using this technique, the effective sizes of the LED and the photo-detector are each reduced to the resolution of an optical fiber, which is typically .5 mm in diameter. Another novel feature of this research the replacement of many photo-resistors with a video camera so as to allow the system to easily scale to a large number of points. These features allow us to optimize the optical fiber proximity sensor for use on a robotic finger.

Optical Fiber Proximity Sensor Theory and Characteristics

The optical fiber proximity sensor works by sending a controlled amount of light down one optical fiber strand and measuring the intensity of the reflected light through an adjacent optical fiber strand. Many of these optical fiber pairs are then bundled together to make an array of these unit proximity sensors. These grouped sensors all work in parallel so that they can receive data simultaneously. Thus the sensor is a multipoint proximity sensor that simultaneously determines the distance from each optical fiber pair.

The multipoint sensor capability is an important feature of the sensor and allows for a detailed high resolution modeling of the target object. This is especially true when the sensor is mounted on a robotic finger in order to manipulate an object. For example, if the robotic finger were used to push an object across a table, it would be able to constantly update how the object moves in response to the applied force. As the object is pushed, the sensor would detect the direction in which the object is moving in response to the applied force. In this feedback system, the robot could then alter and adjust the way the force is applied.

The sensor system built has a high resolution map of nearby objects through the use of thin optical fiber pairs. Because each fiber has only 0.5 mm cross sectional diameter, the optical fibers can be packed closely together so inter-fiber void, where sensor will not register, is minimized. This way, our sensor arrangement is similar to a human fingertip where the sensing nerve endings of the finger are tightly packed yielding very fine tactile resolution.

Finally, the optical fiber proximity sensor has no moving parts, making it inherently robust. Most existing proximity sensors have airgaps, compliant surfaces, or moving parts that can be damaged[4,5]. Furthermore, this sensor is solid state and completely optically based, making it is less costly to produce and relatively easier to manufacture and maintain as compared with other sensor technologies.

In summary, the advantages of our novel optical fiber sensor include multipoint sensing, variable resolution, scalability, robustness, and economical to build and easy to produce.

Software and Data Processing

Using the web camera allows for many data points to be read simultaneously and inexpensively. The data received by the camera and the output displayed is shown in Figure 5. The higher intensity circles reflect objects that are closer to a sensor pair.

The software first determines the maximum and minimum amount of light that is reflected back at each pixel group on the camera through a calibration process. These values are then used to normalize the light intensities received from each optical fiber

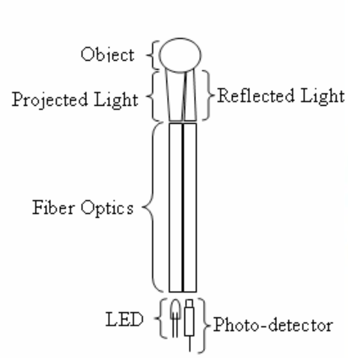

Figure 3. Schematic of light path.

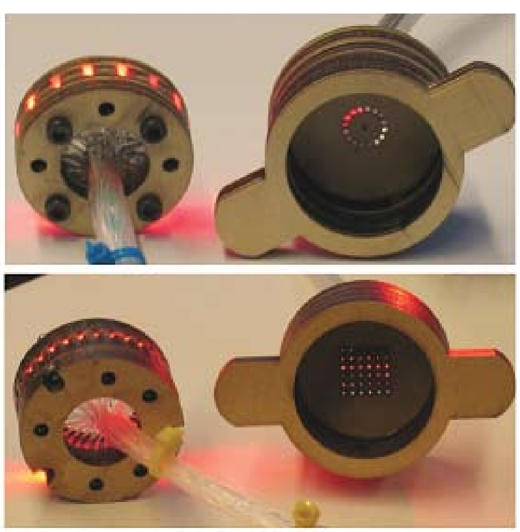

Figure 4. Two different versions of the optical fiber proximity sensor. On the left in both photos is the sensor. On the right is what is mounted over the web camera. It this picture, the web camera would be able to detect the table by determining which receiving fiber optics were transmitting light.

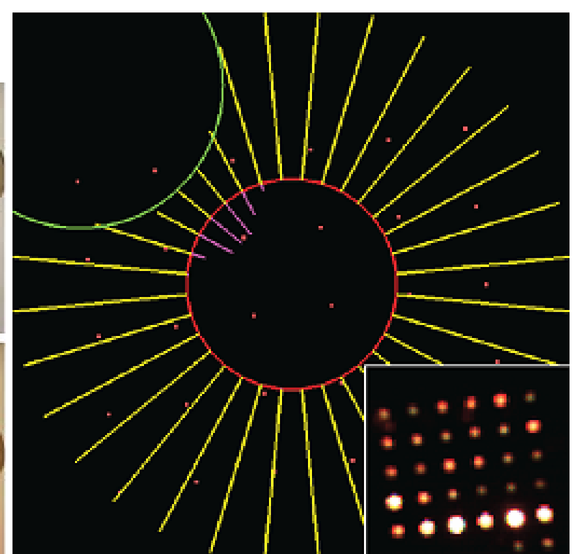

Figure 5. A display of the graphical output of the software. The length of the lines radiating from the red circle are inversely proportional to how much light is transmitted from the receiving fiber optic for that given location. Inset is the raw image received from the camera.

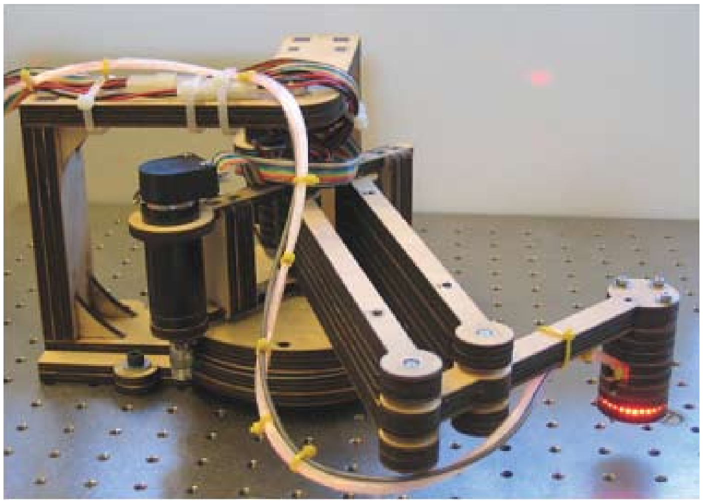

Figure 6. The robotic arm on which the optical fiber proximity sensor was tested.

pair.

After the sensor is calibrated, stray light from other light sources is filtered out. The two main sources of contaminating light are from windows and overhead lighting. Since both of these sources are approximately white light, the software filters out the white light to determine how much red light is being reflected from the object. Additionally, if any of the optical fiber pairs makes contact with the object, the intensity of the reflected light will increase. Thus, the proximity sensor can also be used as a touch sensor.

Conclusion and Future Work

We have proposed and implemented a new type of optical fiber proximity sensor[6]. This sensor is integrated into a robotic finger that is mounted onto a robotic arm, as shown in Figure 6. Initial tests with different target materials were conducted in order to measure the relationship between the intensity of light reflected and the distance of the material from the sensor. From these tests, the sensor is calibrated for the target material. Our results show that the calibrated sensor works well in determining the distance of the object from the sensor.

The optical fiber proximity sensor we presented in this paper has a number of advantages over more traditional capacitive and resistive sensors. These advantages include an ability to sense multiple points at the same time with a variable resolution and scalability. The sensor is also robust against failure, easy to produce, and relatively inexpensive.

Our array of small proximity sensors has many applications beyond the robotic finger used in our experiments. One envisioned application is for a robotic finger to move quickly to explore a large area until it senses the proximity of another object. When it senses it is in another object's proximity, the sensor would then determine the shape of the object and send this information to the robot which in turn would determine the best way to grasp or move the object. The benefit of this arrangement is that the contours of the object can be mapped and explored to determine the best course of action, all before the robot actually touches the object.

Further extensions to our system include changing the light of the sensors from red light to infrared light. With this new choice of frequency for the light from our sensors, we predict there will be less interference from ambient light. Also, the fiber optics could be embedded into a piece of clear latex and then stretched over a surface to give sensitive skin to metallic robotic parts[1]. This would impart sense proximity to the robot so that it could better navigate its environment. We hope to pursue these possibilities in our future work.

Acknowledgments

The idea of using optical fibers in a proximity and touch sensor is inspired by my previous research with optical fiber systems. The current paper is based on joint research with Professor J. Kenneth Salisbury, Sean Walker, Kevin Loewke, and Carl Liu as reported in [6]. I would like to thank Professor Salisbury for supporting my research as an independent study at Stanford during the spring quarter of 2006.

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Combination of Experts

An Approach to Image Boundary Detection

By David Cohen and Jim Rodgers

Introduction and Background

Boundary detection in two-dimensional images is an important problem in computer vision. There are a wide variety of algorithms to accomplish this task, but none has come close to human proficiency. In this paper we will explore a variety of ways to use machine learning algorithms to combine existing boundary detection algorithms with the goal of exceeding the performance of any particular algorithm. We present methods using Adaboost and linear regression and show favorable results produced by them.

Boundary detection is a classification problem which entails labeling a subset of pixels in an image as part of an edge that separates two objects. However, there is no clear definition for which objects should be separated. The most common approach is to attempt to find a set of edges which a human being would consider reasonable. Nonetheless, for any given image, there may be disagreement among human beings as to what set of edges best captures the image. Additionally, while some boundary detection algorithms impose hard boundaries, others instead provide probabilities that each pixel in an image is part of an edge.

Boundary detection, an active research area within the artificial intelligence field of computer vision, has a variety of applications to higher-level vision tasks. Many object-recognition algorithms use image boundaries as inputs. Furthermore, boundary detection algorithms help show the precise orientation of an object in space, which is useful for robotic manipulation tasks. This approach to boundary detection is particularly interesting to us, since we are working on an MRF-based image segmentation algorithm that takes the output from a boundary detection algorithm as its input. Thus, this project could provide better inputs for image segmentation. Alternatively, it may allow us to combine the image segmentation algorithm's boundary output with other boundary detection algorithms' outputs for even better results.

Methodology

Our goal is to predict which pixels in an image fall are edges between objects in that image. Unfortunately, as noted above, there is no clear definition of an edge in an image. Further, even when human beings agree on edges, they often disagree on precisely which pixels in an image correspond to them. To account for this, we use soft boundary maps computed from the edges selected by a number of human subjects as our ground truth. Similarly, we use our algorithms to produce soft edge maps, which we evaluate by applying various threshold values, thinning wide edges, and measuring the quality of each of the resulting thin hard edge maps. We evaluate these edge maps using:

$$\textit{precision} = P(\textit{point is an edge in the ground truth image} \mid \textit{point is predicted as edge}) \quad (1)$$

$$\textit{recall} = P(\textit{point is predicted as edge} \mid \textit{point is an edge in the ground truth image}) \quad (2)$$

$$\textit{f-score} = \frac{2 * \textit{precision} * \textit{recall}}{\textit{precision} + \textit{recall}} \quad (3)$$

Plotting precision and recall for each threshold value produces a curve which characterizes an algorithm's behavior, and the maximum f-score of the data points plotted yields a single number which summarizes the algorithm's success.

Experts and Features

We combine the results of currently existing boundary detection algorithms to produce our edge predictions. We assemble a large number of boundary detection algorithms and experiment with methods of combining them to produce a single boundary map. Our set of boundary detection algorithms currently includes six hard-threshold classifiers which produce logical boundary maps and five probabilistic classifiers which produce soft boundary maps, associating each pixel with the probability it is an edge. Some of the soft edge maps are drawn from [1]. Five of the hard-threshold methods and all of the soft-threshold methods approximate gradients in the image and predict edges at points which correspond to local maxima of the gradient. The two remaining detection methods are a Laplacian of Gaussian algorithm which selects points where the Laplacian of the image changes its sign, and Felzenszwalb's graph-based image segmentation algorithm[2] which merges regions of an image based on their variations in intensity. By varying the parameters of these algorithms, such as threshold values and filter sizes, and by varying the image channel on which these algorithms are run (red, green, blue, or grayscale), we produce 91 different edge maps for each original image. We call each parameterization of a boundary detector on each image channel an *expert*.

In order to learn from our experts, we consider the problem of classifying a single pixel as an edge or non-edge point based on its treatment in the experts' edge maps. Since each expert produces one edge map per image, it contributes exactly one feature for each pixel. We experimented with three different methods for extracting features from experts' edge maps. Let $f_a(x,y,e)$ be the feature extracted by algorithm a from expert e for pixel (x,y), and let M_e be the edge map produced by expert e. In our first feature extraction method, *direct extraction*, $f_{direct}(x,y,e)$ takes the value $M_e(x,y)$. For *Euclidean distance extraction*, $f_{dist}(x,y,e)$ has the value of the Euclidean distance in M_e between *(x,y)* and the nearest edge pixel in the edge map. In *Gaussian distance extraction*, $f_{gaussian}(x,y,e)$ takes the value $exp(-f_{dist}(x,y,e)^2 / v)$ where v is the variance of our Gaussian distribution. We experiment with several such variances.

In constructing training sets, we vary the ratio of edge pixels to non-edge pixels in our training set. We create non-balanced training sets by randomly sampling pixels from our training images, and we label a pixel as an edge if it falls within a one pixel radius of any pixel with a non-zero value in the ground truth edge map. These training sets are composed of approximately 200 edge pixels and 800 non-edge pixels for each image. We also create balanced data sets by sampling 500 edge pixels and 500 non-edge pixels from each image.

Learning Algorithms

We explore several learning algorithms to combine the predictions of our experts. The two most successful of these was real-valued Adaboost, followed by least-squares linear regression. Real-valued Adaboost is an iterative algorithm that converts features into classifiers by choosing the specific feature and threshold with maximal performance on a weighted version of the training set. For example, one such classifier might be:

At each iteration, Adaboost reweights the training set to in-

$$prediction = \begin{cases} edge & \text{if feature } k > \text{threshold } t \\ non\text{-}edge & \text{otherwise} \end{cases}$$

crease the importance of data instances misclassified by the newly chosen classifier. The result of running Adaboost for n iterations is a linear combination of n classifiers, with coefficients determined by the accuracy of each classifier on the weighted data set. This linear combination of classifiers is then applied to test data.

The other successful algorithm we find is least-squares linear regression, which finds the linear combination of the features that minimizes the squared error of feature-value predictions. Unlike Adaboost, which attempts to directly classify data instances, linear regression estimates an arbitrary real-valued function with a line through d-dimensional space, where d is the number of features. We use linear regression to estimate the same features in the test data that we calculate in the training data: raw pixel value, Euclidean distance, or Gaussian distance.

Results

We train and test our algorithms on twenty images from the training set and test set, respectively, provided by the Berkeley Segmentation Dataset[4]. Figure 1 shows a sample of our results on some of the images. We find that Adaboost performs the best of all the algorithms, both visually and according to the f-score. When trained on a balanced data set based on Gaussian distance features with a standard deviation of 2 pixels, Adaboost achieved an f-score of 0.67. We note that this exceeds the f-score of our best expert by 0.04, but also that this particular expert achieved that score when tested on a 100 image test set. This indicates a small performance gain over the baseline.

We find that the most significant factor in our success with Adaboost was the use of a balanced training set, observing that all of our experiments with different features over balanced da-

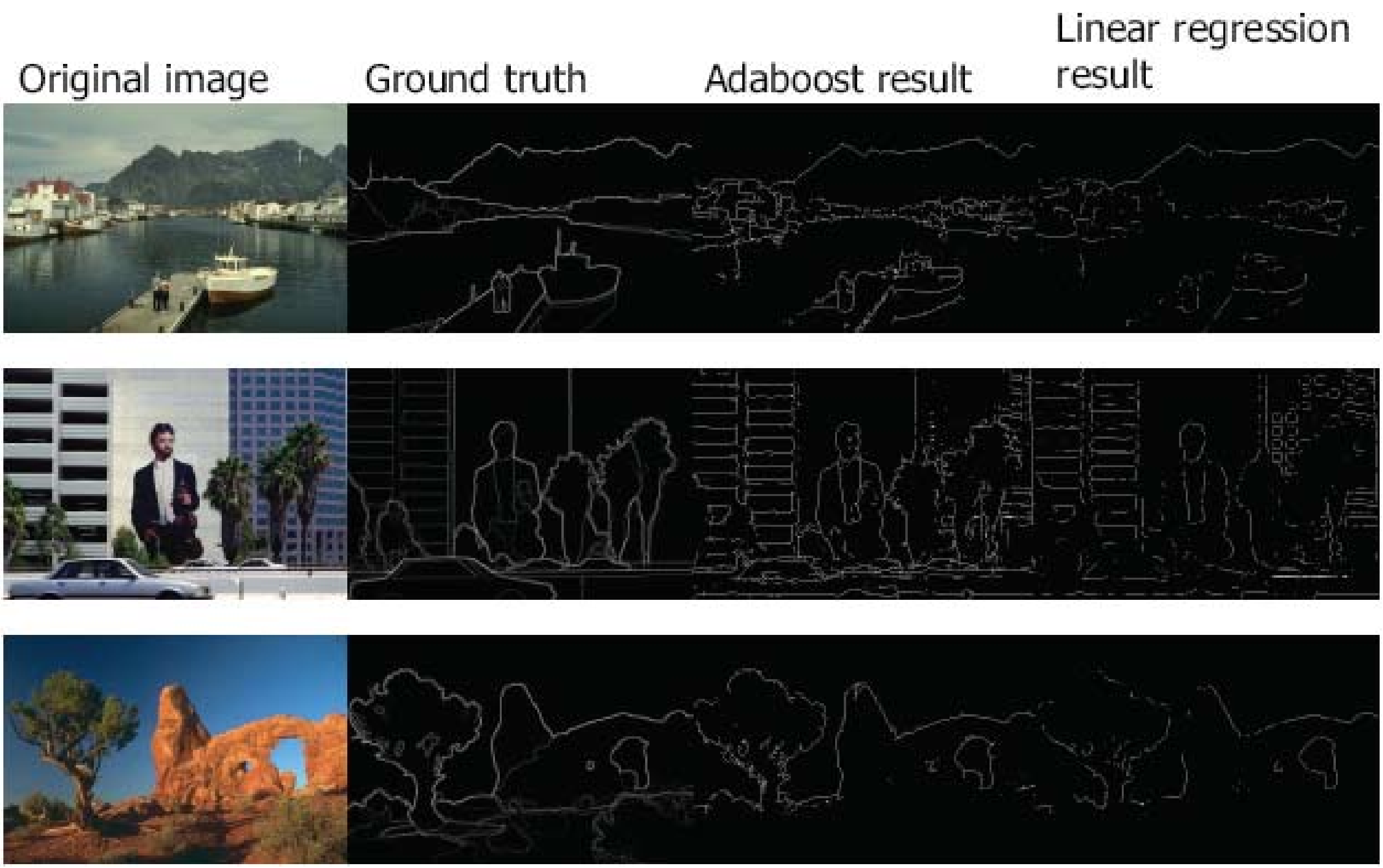


Figure 1: Sample results of running Adaboost and linear regression on the original image, and a comparison with the human-generated ground truth.

tasets scored at or above 0.60, and all Adaboost runs with non-balanced training sets scored at or below 0.56. We believe that this result arises from the ratio of edge points to non-edge points, rather than the absolute numbers of edge or non-edge points. As evidence, we note that our f-score on a balanced Gaussian distance dataset (with standard deviation of 4 pixels) only dropped by 0.01 when we halved the number of training examples used. This highlights the distinction between our objective function, the accuracy, and our evaluation mechanism, the f-score. The distinguishing characteristic of the f-score is that it completely ignores true negatives: the number of non-edge points correctly classified by an algorithm does not affect its f-score, though misclassifying non-edge points as edge-points does lower an algorithm's f-score. The f-score captures the intuition that edges are more important than non-edges in an edge map, and accounts for the fact that the number of edge points in an image varies linearly with its scale, whereas the number of non-edge points varies quadratically. Adaboost yields similar accuracy on both types of training sets, but both the f-scores and the visual appearance of the results on non-balanced sets are inferior.

Least-squares linear regression produces results that are not as good as those we obtain with Adaboost (see Figure 2), but that are nonetheless reasonable. The composition of the training set has little impact on the results. We believe that this is consistent with the non-classification nature of linear regression. The idea of balancing the training set between edges and non-edges is less meaningful when dealing with an algorithm that does not attempt to match edge/non-edge labels, but rather matches the real-valued feature that corresponds to any given ground truth pixel. Linear regression performs similarly with Gaussian distance and direct

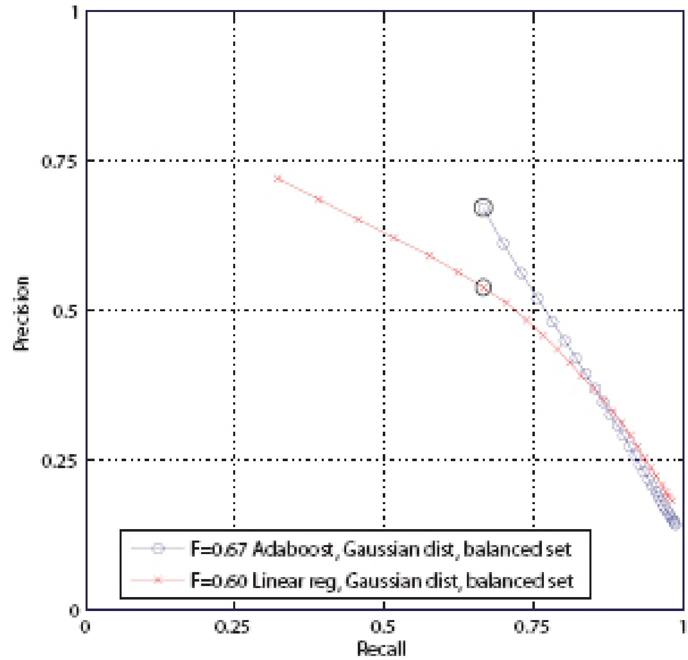
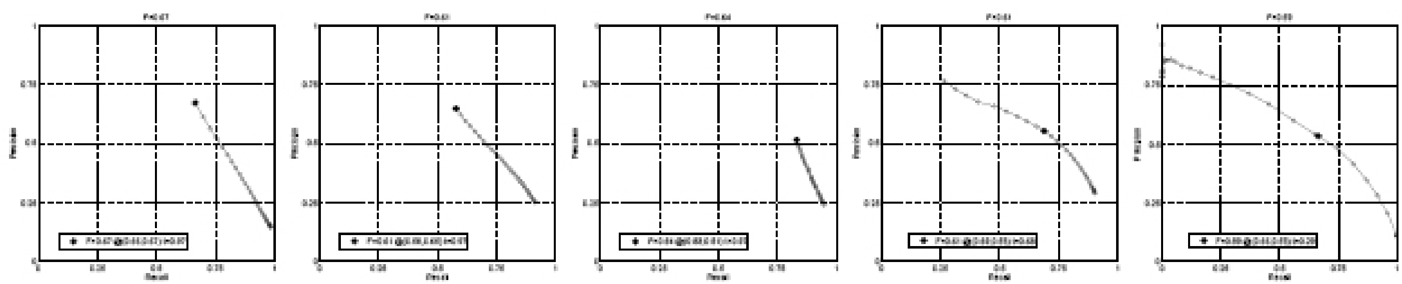


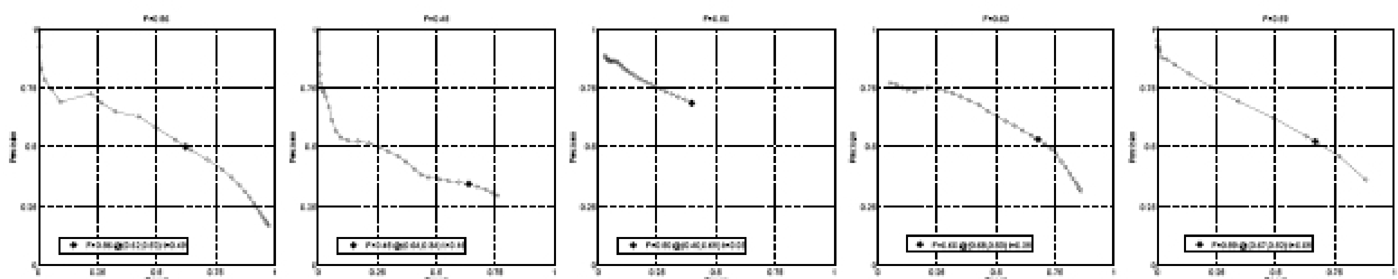
Figure 2: Precision and recall curves for best Adaboost and linear regression results. Adaboost performs better than linear regression

pixel values as features. It performs very poorly with Euclidean distance as a feature, yielding edge maps that predict edges almost everywhere. We achieve the best results, 0.61, with Gaussian features and standard deviation of 4 pixels. Figure 3 shows Precision-Recall curves for Adaboost and linear regression using different training sets and feature composition.

In addition to Adaboost and linear regression, we explore



(a) Adaboost, Gaussian distance, balanced set (F=0.67) (b) Adaboost, Euclidean distance, balanced set (F=0.61) (c) Adaboost, direct pixel value, balanced set (F=0.64) (d) Linear regression, Gaussian distance, balanced set (F=0.61) (e) Linear regression, direct pixel value, balanced set (F=0.59)



(f) Adaboost, Gaussian distance, unbalanced set (F=0.56) (g) Adaboost, Euclidean distance, unbalanced set (F=0.45) (h) Adaboost, direct pixel value, unbalanced set (F=0.50) (i) Linear regression, Gaussian distance, unbalanced set (F=0.60) (j) Linear regression, direct pixel value, unbalanced set (F=0.59)

Figure 3: Precision-Recall curves and their maximum F-score for different combinations of features and training set composition. Best performance is with Adaboost, Gaussian distance, and a balanced training set.

support vector machines (SVMs) and locally weighted linear regression. Neither produce acceptable results. We train SVMs, using the SVMlight package[3], on balanced and unbalanced data sets using pixel values and Euclidean distance features and obtain very poor recall scores. Furthermore, we find a large number of support vectors during SVM training, which hurts SVM performance. Locally weighted linear regression yields no obvious visual differences from standard linear regression when run with a wide variety of bandwidth values, while massively increasing runtime. Whereas standard linear regression produces only one set of parameters, locally weighted linear regression learns new parameters for every pixel in the test set, and thus appears intractable in the context of edge detection.

Conclusion and Future Work

We conclude that Adaboost is a suitable method for combining expert predictions for the image boundary detection problem. Not only does it appear that our current Adaboost classifier may perform better than all of its component experts (we have yet to confirm this by testing on the full Berkeley test set), our findings also offer several avenues for further improvement. First, we achieved a large improvement by changing the composition of our training set, but have not attempted to find the optimal training set edge to non-edge ratio. Further exploration of training set composition may continue to improve our results. Second, we found significant f-score differences based on the variance used for Gaussian distance features, and would like to find the optimal variance using cross-validation. Furthermore, we currently optimize the accuracy and evaluate performance on the f-score, but boosting may allow us to optimize the f-score directly, and thus improve our results. Also, we wish to incorporate knowledge of the softness of our ground truth edge maps by weighting edge pixels by their ground truth pixel values, and thus force our algorithm to favor correct predictions on the stronger edges. Finally, we wish to gather more experts for use in Adaboost and explore more methods for extracting features. Adding more experts and features, especially ones significantly different from those currently used, may improve the resulting edge maps.

Acknowledgements

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Waterfall-Generated Earth Vibrations

A Second Look

By Austin D. Haugen AND Jarupon P. Sathira
In Conjunction With Faculty Advisor Antony C. Fraser-Smith

Introduction

Waterfalls generate a natural frequency as they crash to the ground below. In *Science*, John S. Rinehart[1] proposed a theory for the frequency. Rinehart suggests that the ground vibrations are caused by individual "turbulent eddies" within the water column hitting the ground separately. He proposed that as the height of the fall increases, the distinct eddies have a greater chance to meld together, thus generating lower frequencies for higher waterfalls. From this, Rinehart theorized that an inverse, linear relationship exists between the height of the waterfall and the natural frequency generated. According to Rinehart, the slope of the line relating the two quantities is 250 m/sec.

There is a notable point of contention within Rinehart's paper, which we have explored in our research. In Reinhart's results, two out of ten data points (Gullfoss Upper and Fort Greeley) are outliers from the proposed linear relationship, and another six data points are tightly clustered. These inconsistencies have motivated a second look at Rinehart's theory and a proposal of a possible alternative.

According to K.V. Beard's paper in the *Journal of Applied Meteorology*[2] large water droplets falling in reduced density air will reach terminal velocity when dropped from a height of 11m. Under normal conditions, water droplets will reach terminal velocity at a slightly lower height, around 8 m. Once water reaches terminal velocity, the droplets can meld together, forming larger and fewer droplets. This decreases the frequency for higher waterfalls and is in concurs with Rinehart's theory. However, melding cannot occur for water that has not yet reached terminal velocity. Therefore, we propose that the frequencies for waterfalls of heights below 8m are constant.

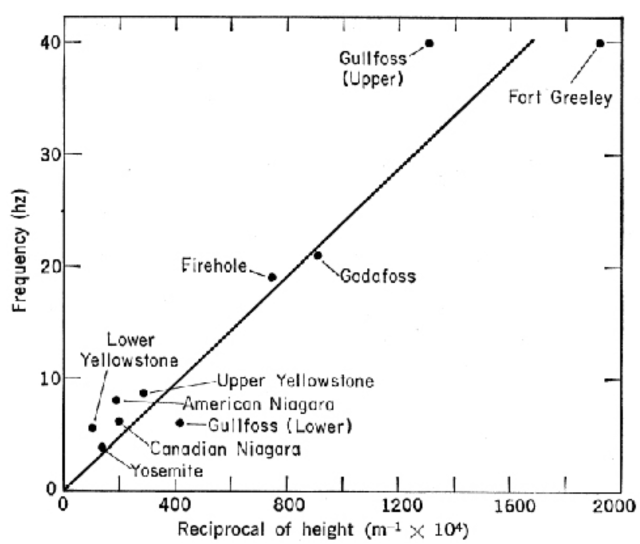


Figure 1. Rinehart's data and proposed line.
Gullfoss (Upper) and Fort Greeley fall far from the line. The six biggest waterfalls are clustered together, casting doubt on the linearity of the data.

The Experiments

One of the problems with collecting data from an actual waterfall is non-uniformity in height and water volume. To obtain consistent data, we began by creating a controlled replica of a waterfall using a water hose. Dropping water from a 1-inch hose at heights ranging from 0.25 m to 8 m, we measured the frequency of the water using two 4 Hz vertical geophones and a geode. We also obtained a second measurement of the frequency of the fall by recording the sound of the water striking the ground. In order to replicate an actual waterfall as closely as possible, we dropped the water onto a 36"x62"x0.3" piece of plywood rather than grass. We accounted for the natural frequency of the wood by placing large stones on the board. This damped out the plywood vibrations, allowing us to determine the resonating frequency of the waterfall. To show that volume of the tap water does not affect the frequency content of the ground vibrations, we increased the volume of water and compared the result with the result from a lower level.

This setup allowed us to address one of the greatest challenges Rinehart faced with data collection. Ramps and ledges of most natural waterfalls often hide the true height of the water fall. In our experimental setup, the water from the hose fell unobstructed to the ground, so we knew exactly what height the water was falling from.

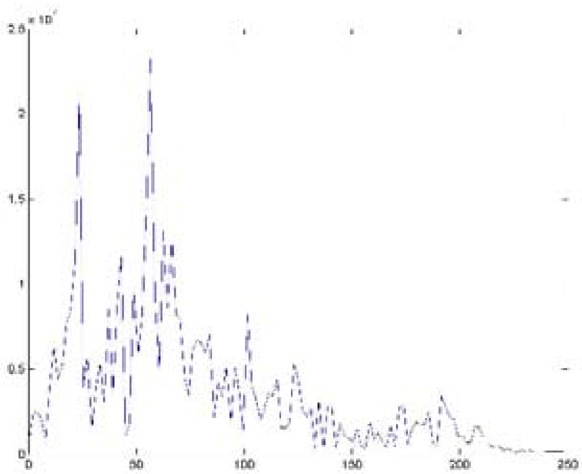
We then measured the vibrations from Granuja Falls in Uvas Canyon Regional Park. We found that the frequency data from the actual waterfall and the hose data from the same height matched. This confirmed that our hose experiment was an accurate representation of a real waterfall.

In each experiment, we collected data at sampling rate of 4000 Hz, 2000 Hz, 1000 Hz, and 500 Hz, in order to catch frequencies up to 2000 Hz while satisfying the Nyquist criterion. Then we analyzed our data using Fast Fourier Transforms on Matlab. The length of the Fourier sequence, nfft, was varied between 27 and 29, with 28 as the default value, to find the best representation of the frequency content of the vibrations.

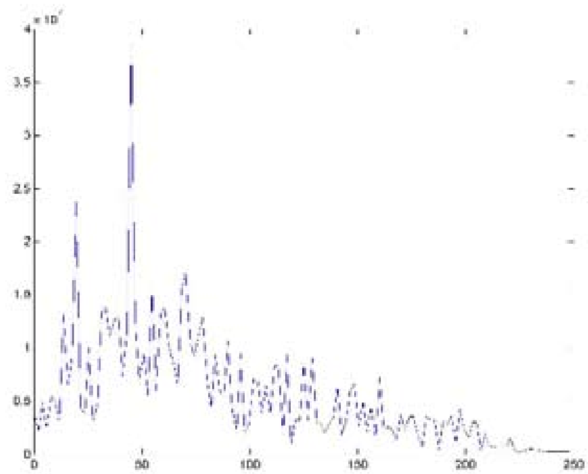
2(a) **2(b)**

Figure 2. (a) The placement of the geophones on the plywood. Plastic bags are used to cover the geophones to prevent problems with the electrical circuit. (b) The hose with water running down to the ground. Note that the plywood is missing.

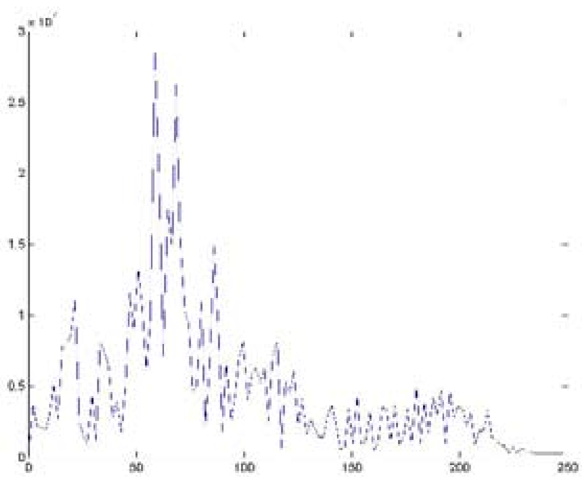
3(a)



3(e)



3(b)



3(f)

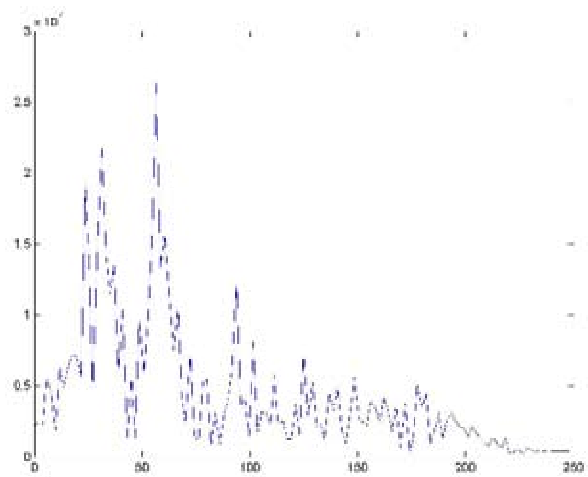


Figure 3. Frequency spectra of ground vibrations excited by a hose at height (a) 1 m, (b) 2 m, (c) 3 m, (d) 4 m, (e) 5 m, and (f) 8 m, sampled at Fs = 500 Hz. All frequency figures in Hz; magnitude for comparison purposes.

Figure 4. Geophones at the bottom of the falls—near and far.

The Experimental Results

1. The Hose Experiments

In the experiment we found that the data has two or three dominant frequencies: 20 Hz, 40-80 Hz, and 80-150 Hz. This characteristic of the frequency spectrum is observed at all heights. The middle peak, at 40-80 Hz, and the first peak, at 20 Hz, are present in every datum but vary in their degree (Relative Velocity Amplitude), while the other peak, at 80-150 Hz, appears frequently but not always (see Figure 3). The first peak is at 20 Hz, which is the resonant frequency of the plywood. Due to the fact that the peak at 20 Hz remains constant regardless of the position of the hose, we propose this is the natural frequency of the plywood. Since the frequency of the second peak, 40-80 Hz, is about half of the frequency of the third one, 80-150 Hz, the third peak can be attributed to the harmonic of the second. In other words, the frequency of 80-150 Hz is merely a harmonic of the predominating frequency of 40-80 Hz.

As illustrated in Figure 3 on the left, the experiments with the hose at varying heights all reveal the same result: a dominant frequency in the range of 40-80 Hz. In contrast to Rinehart's theory, the results do not show any clear relationship between the height of the fall and its frequency.

2. Granuja Falls

Granuja Falls is one of the waterfalls in Uvas Canyon Regional Park. It is 1.8 m in height and about 2 m wide. It runs through out the year but has the most water in winter.

As shown in Figure 5, Granuja Falls has a dominant frequency of 38.90 Hz, but also has minor fluctuations in the 40-80 Hz range. These fluctuations, like the third peak in the hose experiment results, could be a harmonic of the 38.90 Hz primary frequency. The Granuja Falls frequency has peaks at 38.90 and 71 Hz which lies in the 40-80 Hz range. This agrees with the results from the hose experiments and, therefore, confirms that the hose experiment is a good replica of an actual waterfall.

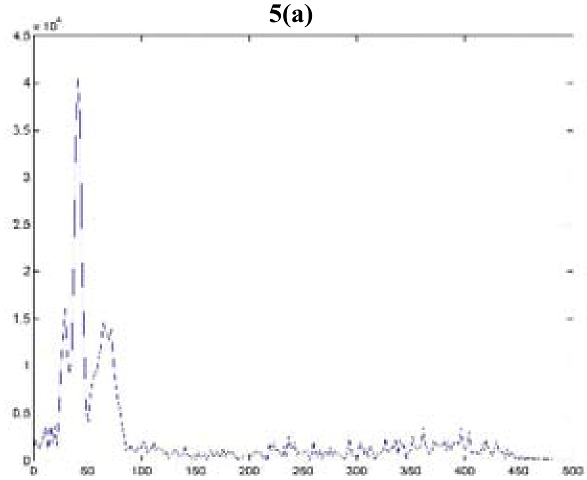
3. All Data Together

A plot of data from our experiments and from Rinehart's study is provided in Figure 6 on the next page. We see that our data lie below Rinehart's line (labeled in red) and form a plateau to the overall trend curve. Granuja Falls frequency of 40 Hz is equal to the frequency of Fort Greeley and that of Gullfoss Upper. Although there are fluctuations in 40-80 Hz range, the new data do not satisfy Rinehart's proposed trend line. The plateau suggests an upper bound to the waterfall vibration frequency at a frequency in the range 40-80 Hz.

Conclusion

While our experiment can only challenge the validity of Rinehart's theory for waterfalls below 8 m, we demonstrated that waterfalls between the heights of 8 m and 0.25 m all have dominant frequencies in the range of 40-80 Hz. Since we cannot disprove Rinehart's results beyond 8 m, we accept his data and linear model up to approximately a height of 8 m. However, we reject his assertion that the linear relationship extends infinitely. Instead, we believe that below a height of 8 m, the frequency plateaus, reaching an upper limit of ~50 Hz. Rinehart recorded that Gullfoss Upper and Fort Greeley Falls, heights of 7.5 m and 5 m respectively, both have a frequency of 40 Hz. He attributes these inconsistencies to the fact that, "the data is not as consistent for low falls"[1]. We are not convinced by Rinehart's explanation, and assert that these two data points are examples of the "plateau" phenomenon we observed: at lower heights the water droplets have not reached terminal velocity.

5(a)



5(b)

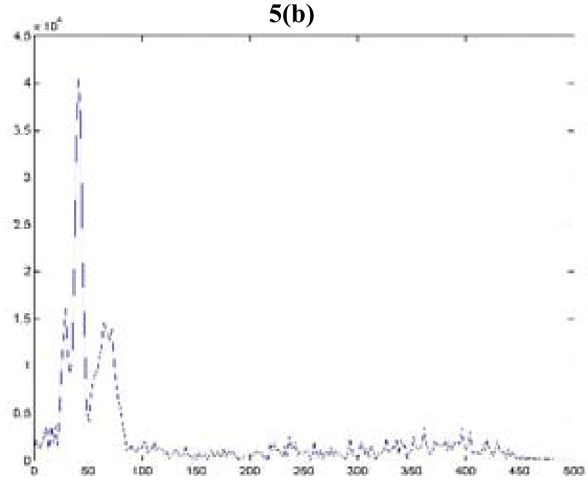


Figure 5. Frequency spectra of ground vibrations generated by Granuja Falls measured at (a) Fs = 1000 Hz and (b) Fs = 500 Hz.m, sampled at Fs = 500 Hz.

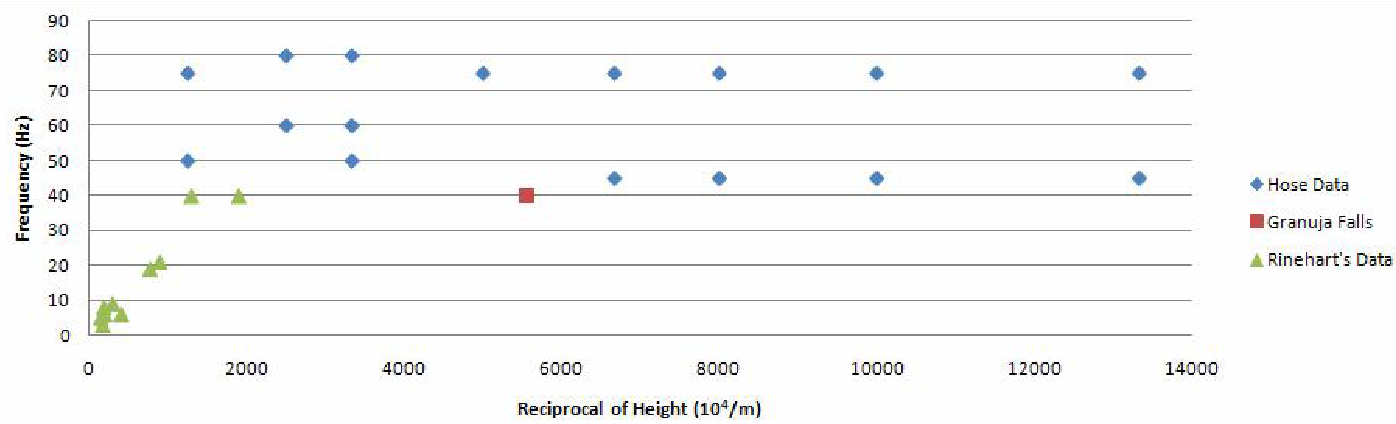


Figure 6. Predominant vibrational frequency as a function of reciprocal of waterfall height

Suggested Work and Application

The wide range of frequencies corresponding to the same height suggests some errors in the experiment. The water column from the hose is small in diameter relative to its height, so factors such as wind, volume of water, water pressure, and human error could have significant impacts on the frequency content of the vibrations

In summary, we conducted a preliminary study relating the frequency of the sound generated by the waterfall with the ground vibration. Our results show that a correlation between the two frequencies exists. This relation could further lead to a prediction of the height of waterfalls in outer space, for example for water falls on Titan. At the same time, we recognize the limitations of our study and agree that there is room for a more comprehensive study of the relation between the sound and the ground vibrations.

References:

[1]Rinehart, John S. “Waterfall-Generated Earth Vibrations.” *Science*. New Series, Vol. 164, No. 3887. (Jun. 27, 1969), pp. 1513-4.

[2]Beard, K. V. “On the Acceleration of Large Water Drops to Terminal Velocity”. *Journal of Applied Meteorology*. Vol. 16, No. 10. (Apr. 11, 1977), pp. 1068–1071.

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Modeling Humans for Physics-Based Graphics and Animation

By Ranjitha Kumar, Josh Liptzin, Joyce Pan, and Mike Rodgers

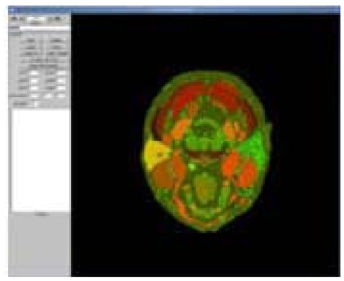
Obtaining Our Model: Assembling a Body

Background

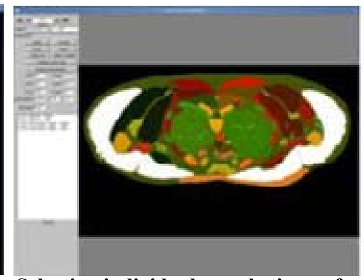
The best way to accurately model a human being for 3D motion is to use an actual human being. A convicted murderer from Texas who was executed (see Texas Chainsaw Massacre) volunteered the use of his body for scientific purposes. He was frozen and cut into 1,876 one-millimeter slices so that his bone, muscle, and other soft tissues could be scanned into the computer. Though only one testicle survived the dicing and slicing, we were still able to accurately model human motion. Luckily, we only had to deal with the raw data and not the raw flesh.

From Bones to Bytes

The data from each slice of the actual human being is stored as a two-dimensional color map, with different colors representing different tissues. After cleaning up the raw data slices, we convert the slices into a three dimensional levelset using the fast marching method. The program we've developed even allows us to select individual bones, tendons, or muscles from the body like the biceps, triceps, or eyeballs and convert only those tissues to a levelset for later use.

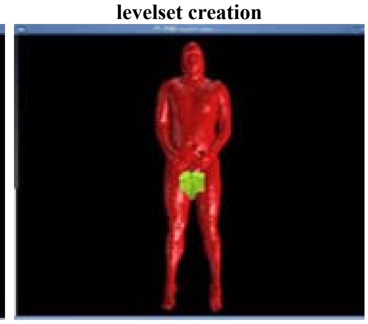


Single slice of a human head



Selecting individual muscle tissues for levelset creation

A full body levelset



A full body mesh created from the levelset to the left

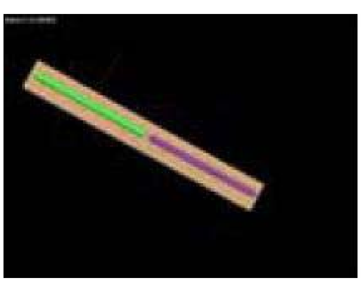
Tetrahedral Meshing

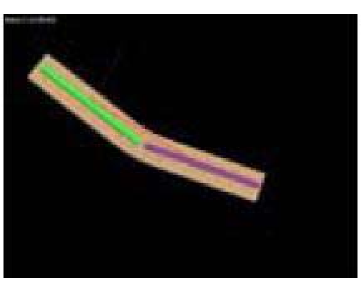
After creating the levelset, we convert it to a tetrahedral mesh so that it's easy to wrap around a skeleton and accurately model for motion. The algorithm we use to create the mesh, which was developed by our faculty mentor Ron Fedkiw and his colleagues, it is well suited for simulation since it is highly structured, has topology chosen specifically for large deformations, and is readily refined if required during subsequent simulation[1].

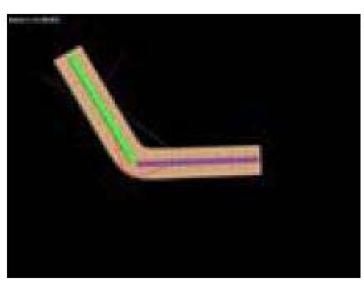
Joining Flesh and Bone: Quasistatic Simulation

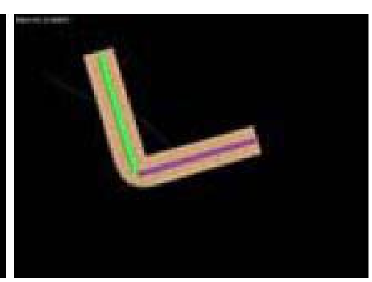
We handle the deformation of soft tissue in our simulations using a technique known as quasistatics. We represent the flesh with a tetrahedralized volume—in our case, a solid composed of

Quasistatic Simulation of a Crude Approximation of an Upper Arm









Frame 0:	Frame 2:	Frame 6:	Frame 64:
• Initial state: muscles (gray) inactive • Record positions of flesh particles embedded within bones • Remaining (non-embedded) particles already experience net force of zero.	• Bicep (red) activates to flex arm • Update embedded flesh particles to remain in same positions relative to bones • Quasistatic calculations resolve positions of remaining (non-embedded) particles	• Tricep (red) activates to decelerate flexing • Update embedded flesh particles to remain in same positions relative to bones • Quasistatic calculations resolve positions of remaining (non-embedded) particles	• Final state reached: muscles (gray) inactive • Update embedded flesh particles to remain in same positions relative to bones • Quasistatic calculations resolve positions of remaining (non-embedded) particles

799,401 tetrahedrons. The vertices of these tetrahedrons are referred to as particles or nodes. We apply a constitutive model to the deformable body in order to define how it retains its shape. The constitutive model is a series of elastic forces connecting the particles, working to preserve the distances between them and thereby keeping constant the volume of each tetrahedron and of the solid as a whole.

After placing our models of the bones inside our soft-tissue mesh, but before initiating the simulation, we make a note of every particle that lies within a bone, and for the duration of the simulation, we constrain that particle to move with that bone. With each time-step evolution of the simulation, we force each constrained particle to retain its initial placement relative to the position and orientation of its parent bone. The positions of the other particles must be determined based upon the forces acting on them. (Primarily, these forces come from the constitutive model, but they can also be from gravity or some other external influence.)

Treating the constrained particle positions as fixed and immutable, we iteratively apply the Newton-Raphson method to determine the positions the remaining particles must adopt in order for the net force upon each particle to be zero. The advantage of this method is that we move the deformable body directly to its final rest state. Therefore, these calculations need only to be performed once per frame, as opposed to alternative methods which require numerous sub-steps between frames. The quasistatic method is not without drawbacks however. Because all motion of the deformable body is treated as taking place at infinite speed, the technique cannot be used to simulate wave-form propagation or any sort of reverberating oscillations, such as skin or muscle "jiggle."

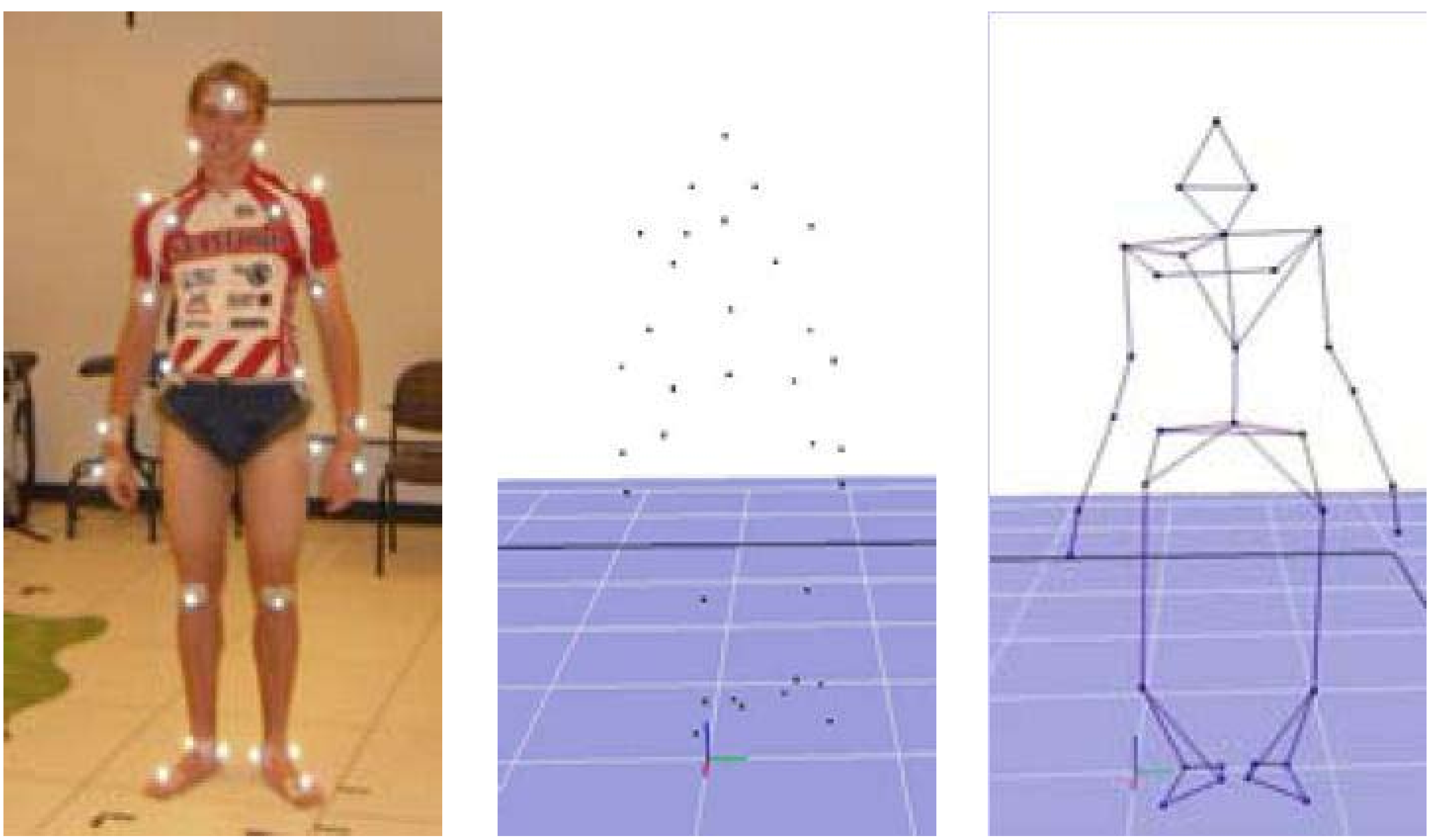
Animating the skeleton: Motion Capture Data

Motion Capture Session

We used motion capture to obtain realistic human motion data to apply to our human model. The procedure consisted of placing 33 reflective markers on our human subject, mostly on joints or bony areas where marker movement would signify joint movement (as opposed to skin or fat). A total of 8 cameras were set up around the motion capture area to track the reflective markers. We then captured and processed the motion of our subject using EVaRT 4.6 by Motion Analysis. The end result was world coordinates for any reflective material within the motion capture area.

Parsing the Data

Our first task was to clean the data. We identified each marker based on its position relative to the body and defined linkages with set distances between them in order to create a template. This helped EVaRT maintain consistent naming of them by assuming that the lengths of the linkages would more or less remain the same. It also allowed the user to visualize human motion from points moving in 3-D space by connecting them into a recognizable frame. Although EVaRT can automatically generate templates for marker sets and apply them throughout the motion capture sequence, we still had to take care of issues such as markers momentarily disappearing (for example, when they were



Obtaining Motion Capture Data: We placed reflective markers on our subject (left) covered with retro-reflective material. The cameras captured the movement of these markers in 3-D space (middle), and EVaRT connected the data points to form a body template (right).

Quasistatic Simulation of a Tetrahedralized Muscle Mesh

Quasistatic Simulataion where the Skin Mesh Deforms with the Muscle

blocked from the cameras) or incorrect marker identification. For incorrect marker identification, we would rename the markers by hand. For missing markers, EVaRT could estimate where markers should go by looking at the markers linked to the missing marker in the template.

Attaching the Data to the Skeleton

The main goal for our motion capture data was to generate joint angles to apply to our virtual human. Initially, we attempted to do this by using EVaRT to generate a skeleton linked to the marker data. We then had the proper software to read in a skeleton file, parse it, and calculate joint angles. However, we ran into issues using EVaRT which made us try for our second option. The second method was to export the marker data as a c3d file, which simply gives the marker names and their world coordinates over time. We then parsed the file and, using another file that tells us what joints are defined by what marker angles, calculated the joint angles and wrote them out to a new file. After we had a file of the joint angles, we wrote a function in our visible human example to read in the joint angles and apply them as tracks for the individual joints to follow. One of the difficulties lay in the definition of joints using our motion capture markers. The joints for the visible human are defined by the bones, and therefore the joint angles are defined by the orientation of the bones relative to each other. While the markers we used in the motion capture session didn't match up exactly with the bones that the virtual human had, our goal was to create realistic human movement, not to mimic the motion capture movement exactly.

Moving the Bones and Bulging the Skin: Muscles

Our goal this summer was to replace muscles originally implemented as line segments with volumetric muscles. The line segment muscles add an additional constraint to the optimization procedure used to determine the impulses exerted on the bones to achieve a target state of the joint. Muscle impulses are only applied at the attachment points, and therefore they are constrained to act along the line of action of the muscle, defined as the line between the attachment points. The force exerted by a muscle is based on the activation which is used as input to the muscle force curve, which is scaled on a per-muscle basis by each muscle's peak force and optimal length.

On top of the line segment muscles, we layer the volumetric ellipsoid meshes. The meshes are created from a tetrahedralized sphere mesh which is scaled and transformed so that its primary axis is aligned with the line of action of its corresponding line segment muscle. After positioning the mesh, particles around the region of the attachment points are constrained to their respective attachment point and maintain their original relative position and orientation for the subsequent steps of the simulation. The remaining particles of the mesh are then simulated with quasistatics.

The next step was to attach the skin mesh to the muscle so that it deformed as the muscle contracted and extended. All the particles in the skin mesh are queried to determine whether or not they intersect with the tetrahedralized muscle mesh. If a particle falls within a tetrahedron of a muscle mesh, its barycentric coordinates within that tetrahedron is stored. In subsequent steps of the simulation these particles of the skin are positioned such that they always maintain the same original barycentric coordinates within the same tetrahedron as the first frame. As the particles within the muscles move, the rest of the skin mesh follows based on its constitutive model (simulated using quasistatics) resulting in the skin deformations shown above.

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