Project planning & system evaluation

Bill MacCartney
CS224U
15 April 2015
Project timeline

Today

Workshop 1:
Project planning & system eval

May 6

Due: Lit review (15%)

May 13

Workshop 2:
Writing up & presenting your work

May 25

Due: Project milestone (10%)

June 1 & 3

Due: In-class presentations (5%)

June 9

Due: Final project paper (30%)
Goals for today

- Get you thinking concretely about what you want to accomplish
- Identify productive steps you can take even if you’re still deciding on a topic or approach
- Try to help you avoid common pitfalls for projects
- Emphasize the importance of planning for system evaluation *early*
- Start building momentum for the final project!!
Inspiration

It’s nice if you do a great job and earn an A on your final project, but let’s think bigger:

- Many important and influential ideas, insights, and algorithms began as class projects.
- Getting the best research-oriented jobs will likely involve giving a job talk. Your project can be the basis for one.
- You can help out the scientific community by supplying data, code, and results (including things that didn’t work!).
Inspiring past projects

See: https://www.stanford.edu/class/cs224u/restricted/past-final-projects/

- Semantic role labeling
- Unsupervised relation extraction
- Solving standardized test problems
- Humor detection
- Biomedical NER
- Sentiment analysis in political contexts
- Learning narrative schemas
- Supervised and unsupervised compositional semantics
- ...

Don’t neglect topics from later in quarter (e.g. semantic parsing)!
Agenda

- Overview
- Lit review
- Data sources
- Project set-up & development
- Evaluation
- Dataset management
- Evaluation metrics
- Comparative evaluations
- Other aspects of evaluation
- Conclusion
The lit review

- A short (~6-page) single-spaced paper summarizing and synthesizing several papers in the area of your final project.

- Groups of one should review 5 papers; groups of two, 7 papers; and groups of three, 9 papers.

- Preferably fuel for the final project, but graded on its own terms.
The lit review: what to include

Tips on major things to include:

● General problem / task definition
● Concise summaries of the papers
● Compare & contrast approaches (most important!)
● Future work: what remains undone?

More details at the homepage [link]
Our hopes

- The lit review research suggests baselines and approaches.
- The lit review helps us understand your project goals.
- We’ll be able to suggest additional things to read.
- The prose itself can be modified for inclusion in your paper.
Finding the literature

The relevant fields are extremely well-organized when it comes to collecting their papers and making them accessible:

- ACL Anthology: http://www.aclweb.org/anthology/
- ACL Anthology Searchbench: http://aclasb.dfki.de/
- ACM Digital Library: http://dl.acm.org/
- Google Scholar: http://scholar.google.com/
Search strategies

- The course homepage is a good starting place!
- Trust the community (to an extent): frequently cited papers are likely to be worth knowing about.
- Consult textbooks & survey papers for tips on how ideas relate to each other.
- Apply “best-first search algorithm” (next slide)
Best-first search algorithm

Until you get a core set of lit review papers:

1. Do a keyword search at ACL Anthology
2. Download the papers that seem most relevant
3. Skim the intros & previous work sections
4. Identify papers that look relevant, appear often, & have lots of citations on Google Scholar
5. Download those papers
6. Return to step 3
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● Conclusion
The importance of data

- Your investigation should be *empirical* — i.e., data-driven
- We are scientists!
  - Well, or engineers — either way, we’re empiricists!
  - Not some hippie tree-hugging philosophers or poets
- You’re trying to solve a real problem
  - Need to verify that your solution solves real problem instances
- So evaluate the output of your system on real inputs
  - Realistic data, not toy data or artificial data
  - Ideally, plenty of it
Sources of data

Three strategies for obtaining data:

1. Find it (the easiest way!)
2. Create it (the laborious way)
3. Pay others to create it (the expensive way)

(Our discussion will focus primarily on labeled data for supervised learning, but applies to unlabeled data too.)
Large data repositories

Linguistic Data Consortium: [http://www.ldc.upenn.edu/](http://www.ldc.upenn.edu/)

- Very large and diverse archive
- Especially rich in annotated data
- Corpora are typically very expensive
  (but see the next slide)


- For-profit data provider
- Lots of free and useful word-lists
- Links to publicly available data (census data, maps, ...)
Stanford Linguistics corpora

- We subscribe to the LDC and so have most of their data sets: http://linguistics.stanford.edu/department-resources/corpora/inventory/

- To get access, follow the instructions at this page: http://linguistics.stanford.edu/department-resources/corpora/get-access/

- When you write to the corpus TA, cc the CS224U course staff address. Don’t forget this step!

- Write from your Stanford address. That will help the corpus TA figure out who you are and how to grant you access.
Twitter API

- https://dev.twitter.com/

- To stream random current tweets into a local file:
  
  ```
  curl http://stream.twitter.com/1/statuses/sample.json -uUSER:PASS
  ```

  I think this will deliver ≈7 million tweets/day.

- But Twitter data requires *extensive* pre-processing:
  - Filter heuristically by language (don’t rely only on “lang” field)
  - Filter spam based on tweet structure (spam warnings: too many hashtags, too many usernames, too many links)
  - Handle retweets in a way that makes sense given your goals
Other APIs

- Yelp: [http://www.yelp.com/developers/documentation](http://www.yelp.com/developers/documentation)
- Stack Exchange: [http://api.stackexchange.com/](http://api.stackexchange.com/)
Scraping

- Link structure is often regular (reflecting database structure)
- If you figure out the structure, you can often get lots of data!
- Once you have local copies of the pages:
  - Beautiful Soup (Python) is a powerful tool for parsing DOMs
  - Readability offers an API for extracting text from webpages
- Use rate limiting / request throttling !!!!!
- Read site policies! Be a good citizen! Don’t get yourself (or your school) banned! Don’t go to jail! You will not like it.
- For more on crawler etiquette, see Manning et al. 2009 (http://nlp.stanford.edu/IR-book/)
Some NLU datasets (open web)

  - Internet Argument Corpus
  - Annotated political TV ads
  - Focus of negation corpus
  - Persuasion corpus (blogs)
- Data Chris has made available as part of other courses and projects:
  - Data/code page: [http://www.stanford.edu/~cgpotts/computation.html](http://www.stanford.edu/~cgpotts/computation.html)
  - Computational pragmatics: [http://compprag.christopherpotts.net](http://compprag.christopherpotts.net)
  - The Cards dialogue corpus: [http://cardscorpus.christopherpotts.net](http://cardscorpus.christopherpotts.net)
Some NLU datasets (on AFS)

Get access from the corpus TA, as described earlier:

- Nate Chambers’ de-duped and dependency parsed NYT section of Gigaword: /afs/ir/data/linguistic-data/GigawordNYT

- Some data sets from Chris:
  - /afs/ir/data/linguistic-data/mnt/mnt4/PottsCorpora
    - README.txt, Twitter.tgz, imdb-english-combined.tgz, opentable-english-processed.zip
  - /afs/ir/data/linguistic-data/mnt/mnt9/PottsCorpora
    - opposingviews, product-reviews, weblogs

- Twitter data collected and organized by Moritz (former CS224Uer!)
  - /afs/ir.stanford.edu/data/linguistic-data/mnt/mnt3/TwitterTopics/
Annotating data

If you can’t find suitable annotated data, you might consider annotating your own data. But:

- The quantity will be small → harder to learn from
- Your evaluations will be less convincing — no comparison to prior work
- It’s a pain in the ass!
- You must not let this be a bottleneck!

Later we’ll discuss crowdsourcing, which is less risky (but more limited in what it can accomplish).
Setting up an annotation project

- Plan to have multiple annotators! (Enlist your friends.)
- Annotate a subset of the data yourself. This will reveal challenges and sources of ambiguity.
- Writing a detailed annotation manual will save you time in the long run, even if it delays the start of annotation.
- Consider a training phase for annotators, following by discussion.
- Consider whether your annotators should be allowed to collaborate and/or resolve differences among themselves.
- brat rapid annotation tool: http://brat.nlplab.org
Assessing annotation quality

- **Cohen’s kappa** is the standard measure of inter-annotator agreement in NLP. It works only where there are exactly two annotators and all of them did the same annotations.

- **Fleiss’ kappa** is suitable for situations in which there are multiple annotators, and there is no presumption that they all did the same examples.

- Both kinds of kappa assume the labels are unordered. Thus, they will be harsh/conservative for situations in which the categories are ordered.

- The central motivation behind the kappa measures is that they take into account the level of (dis)agreement that we can expect to see by chance. Measures like “percentage choosing the same category” do not include such a correction.
Sources of uncertainty

- Ambiguity and vagueness are part of what make natural languages powerful and flexible.
- However, this ensures that there will be uncertainty about which label to assign to certain examples.
- Annotators might speak different dialects, and thus have different linguistic intuitions.
- Such variation will be systematic and thus perhaps detectable.
- Some annotators are just better than others.
Pitfalls

- Annotation projects almost never succeed on the first attempt. This is why we don’t really encourage you to start one now for the sake of your project.

- (Crowdsourcing situations are an exception to this, not because they succeed right way, but rather because they might take just a day from start to finish.)

- Annotation is time-consuming and expensive where experts are involved.

- Annotation is frustrating and taxing where the task is filled with uncertainty. Uncertainty is much harder to deal with than a simple challenge.
Crowdsourcing

If ...

- You need new annotations
- You need a *ton* of annotations
- Your annotations can be done by non-experts

... crowdsourcing might provide what you need, provided that you go about it with care.
The original Mechanical Turk

Advertised as a chess-playing machine, but actually just a large box containing a human expert chess player.

So Amazon’s choice of the name “Mechanical Turk” for its crowdsourcing platform is appropriate: humans just like you are doing the tasks, so treat them as you would treat someone doing a favor for you.

http://en.wikipedia.org/wiki/The_Turk
Crowdsourcing platforms

There are several, including:

- Amazon Mechanical Turk: https://www.mturk.com/
- Crowdflower (handles quality control): http://crowdflower.com/
- oDesk (for expert work): https://www.odesk.com
Who turks?

Papers

- Munro and Tily (2011): history of crowdsourcing for language technologies, along with assessment of the methods
- 2010 NAACL workshop on crowdsourcing: [http://aclweb.org/anthology-new/W/W10/#0700](http://aclweb.org/anthology-new/W/W10/#0700)
- Snow et al. (2008): early and influential crowdsourcing paper: crowdsourcing requires more annotators to reach the level of experts, but this can still be dramatically more economical
- Hsueh et al. (2009): strategies for managing the various sources of uncertainty in crowdsourced annotation projects
Managing projects on MTurk

If you’re considering running a crowdsourcing project on Mechanical Turk, please see *much* more detailed slides from last year’s slide deck:


And consult with Chris, who has experience in this!
Will crowdsourcing work?

- One hears that crowdsourcing is just for quick, simple tasks.
- This has not been our (Chris') experience. We have had people complete long questionnaires involving hard judgments.
- To collect the Cards corpus, we used MTurk simply to recruit players to play a collaborative two-person game.
- If you post challenging tasks, you have to pay well.
- There are limitations, though:
  - If the task requires any training, it has to be quick and easy (e.g., learning what your labels are supposed to mean).
  - You can’t depend on technical knowledge.
  - If your task is highly ambiguous, you need to reassure workers and tolerate more noise than usual.
In-class assignment

Let’s get the ball rolling! Please take a few minutes to post a project idea on Piazza. You can post:

- to the full class, using “Search for Teammates!”, or
- to the full class, as a regular post, or
- just to the instructors.

Briefly describe:

- Your current project idea, if you have one.
- Or, a topic or area of interest. (Not binding!)
- Data needs you expect your project to have.
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Project set-up

Now that you’ve got your dataset more or less finalized, you can start building stuff and doing experiments!
Data management

- It will pay to get your data into an easy-to-use form and write general code for reading it.
- If your data-set is really large, considering putting it in a database or indexing it, so that you don’t lose a lot of development time iterating through it.
Automatic annotation tools

- If you need additional structure — POS tags, named-entity tags, parses, etc. — add it now.

- The Stanford NLP group has released lots of software for doing this: http://nlp.stanford.edu/software/index.shtml

- Can be used as libraries in Java/Scala. Or, can be used from the command-line.

- Check out CoreNLP in particular — amazing!
Conceptualizing your task

<table>
<thead>
<tr>
<th>Representation</th>
<th>Evaluation</th>
<th>Optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instances</td>
<td>Accuracy/Error rate</td>
<td>Combinatorial optimization</td>
</tr>
<tr>
<td>K-nearest neighbor</td>
<td>Precision and recall</td>
<td>Greedy search</td>
</tr>
<tr>
<td>Support vector machines</td>
<td>Squared error</td>
<td>Beam search</td>
</tr>
<tr>
<td>Hyperplanes</td>
<td>Likelihood</td>
<td>Branch-and-bound</td>
</tr>
<tr>
<td>Naive Bayes</td>
<td>Posterior probability</td>
<td>Continuous optimization</td>
</tr>
<tr>
<td>Logistic regression</td>
<td>Information gain</td>
<td>Unconstrained</td>
</tr>
<tr>
<td>Decision trees</td>
<td>K-L divergence</td>
<td>Gradient descent</td>
</tr>
<tr>
<td>Sets of rules</td>
<td>Cost/Utility</td>
<td>Conjugate gradient</td>
</tr>
<tr>
<td>Propositional rules</td>
<td>Margin</td>
<td>Quasi-Newton methods</td>
</tr>
<tr>
<td>Logic programs</td>
<td></td>
<td>Constrained</td>
</tr>
<tr>
<td>Neural networks</td>
<td></td>
<td>Linear programming</td>
</tr>
<tr>
<td>Graphical models</td>
<td></td>
<td>Quadratic programming</td>
</tr>
<tr>
<td>Bayesian networks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditional random fields</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Domingos 2012
Off-the-shelf modeling tools

While there’s some value in implementing algorithms yourself, it’s labor intensive and could seriously delay your project. We advise using existing tools whenever possible:

- Stanford Topic Modeling Toolbox (Scala): [http://nlp.stanford.edu/software/tmt/tmt-0.4/](http://nlp.stanford.edu/software/tmt/tmt-0.4/)
- MALLET (Java): [http://mallet.cs.umass.edu/](http://mallet.cs.umass.edu/)
- FACTORIE (Scala): [http://factorie.cs.umass.edu/](http://factorie.cs.umass.edu/)
- GATE (Java): [http://gate.ac.uk/](http://gate.ac.uk/)
Iterative development

Launch & iterate!

- Get a baseline system running on real data ASAP
- Implement an evaluation — ideally, an automatic one, but could be more informal if necessary
- Hill-climb on your objective function
- Focus on feature engineering (next slide)

Goal: research as an “anytime” algorithm: have some results to show at every stage
The feature engineering cycle

1. **Add new features**
2. **Evaluate on development dataset**
3. **Identify categories of errors**
4. **Brainstorm solutions**
5. **Error analysis**
Focus on feature engineering

- Finding informative features matters more than choice of classification algorithm
  
  Domingos (2012:84): “At the end of the day, some machine learning projects succeed and some fail. What makes the difference? Easily the most important factor is the features used.”

- Do error analysis and let errors suggest new features!
- Look for clever ways to exploit new data sources
- Consider ways to combine multiple sources of information
More development tips

- Construct a tiny toy dataset for development
  - Facilitates understanding model behavior, finding bugs

- Consider ensemble methods
  - Develop multiple models with complementary expertise
  - Combine via max/min/mean/sum, voting, meta-classifier, ...

- Grid search in parameter space can be useful
  - Esp. for “hyperparameters”
  - Esp. when parameters are few and evaluation is fast
  - A kind of informal machine learning
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Why does evaluation matter?

In your final project, you will have:

- Identified a problem
- Explained why the problem matters
- Examined existing solutions, and found them wanting
- Proposed a new solution, and described its implementation

So the key question will be:

- Did you solve the problem?

The answer need not be yes, but the question must be addressed!
Who is it for?

Evaluation matters for many reasons, and for multiple parties:

- For future researchers
  - Should I adopt the methods used in this paper?
  - Is there an opportunity for further gains in this area?

- For reviewers
  - Does this paper make a useful contribution to the field?

- For yourself
  - Should I use method/data/classifier/... A or B?
  - What’s the optimal value for parameter X?
  - What features should I add to my feature representation?
  - How should I allocate my remaining time and energy?
The role of data in evaluation

- Evaluation should be *empirical* — i.e., data-driven

- We are scientists!
  - Well, or engineers — either way, we’re empiricists!
  - Not some hippie tree-hugging philosophers or poets

- You’re trying to solve a real problem
  - Need to verify that your solution solves real problem instances

- So evaluate the output of your system on real inputs
  - Realistic data, not toy data or artificial data
  - Ideally, plenty of it
Kinds of evaluation

- Quantitative
  - Automatic
  - Intrinsic
  - Formative

- Qualitative
  - Manual
  - Extrinsic
  - Summative
Quantitative vs. qualitative

- Quantitative evaluations should be primary
  - Evaluation metrics — *much* more below
  - Tables & graphs & charts, oh my!

- But qualitative evaluations are useful too!
  - Examples of system outputs
  - Error analysis
  - Visualizations
  - Interactive demos
    - A great way to gain visibility and impact for your work
    - Examples: OpenIE (relation extraction), Deeply Moving (sentiment)

- A tremendous aid to your readers’ understanding!
Examples of system outputs

<table>
<thead>
<tr>
<th>Relation name</th>
<th>New instance</th>
</tr>
</thead>
<tbody>
<tr>
<td>/location/location/contains</td>
<td>Paris, Montmartre</td>
</tr>
<tr>
<td>/location/location/contains</td>
<td>Ontario, Fort Erie</td>
</tr>
<tr>
<td>/music/artist/origin</td>
<td>Mighty Wagon, Cincinnati</td>
</tr>
<tr>
<td>/people/deceased_person/place_of_death</td>
<td>Fyodor Kamensky, Clearwater</td>
</tr>
<tr>
<td>/people/person/nationality</td>
<td>Marianne Yvonne Heemskerk, Netherlands</td>
</tr>
<tr>
<td>/people/person/place_of_birth</td>
<td>Wavell Wayne Hinds, Kingston</td>
</tr>
<tr>
<td>/book/author/works_written</td>
<td>Upton Sinclair, Lanny Budd</td>
</tr>
<tr>
<td>/business/company/founders</td>
<td>WWE, Vince McMahon</td>
</tr>
<tr>
<td>/people/person/profession</td>
<td>Thomas Mellon, judge</td>
</tr>
</tbody>
</table>

Table 1: Ten relation instances extracted by our system that did not appear in Freebase.
Examples of system outputs

<table>
<thead>
<tr>
<th>relation</th>
<th>paths</th>
</tr>
</thead>
<tbody>
<tr>
<td>entertainment</td>
<td>A, who play B:30; A play B:30; star A as B:30</td>
</tr>
<tr>
<td>sports</td>
<td>lead A to victory over B:20; A play to B:20; A play B:20; A’s loss to B:20; A beat B:20; A trail B:20; A face B:26; A hold B:26; A play B:26; A acquire (X) from B:26; A send (X) to B:26;</td>
</tr>
<tr>
<td>politics</td>
<td>A nominate B:39; A name B:39; A select B:39; A name B:42; A select B:42; A ask B:42; A choose B:42; A nominate B:42; A turn to B:42;</td>
</tr>
<tr>
<td>law</td>
<td>A charge B:39; A file against B:39; A accuse B:39; A sue B:39</td>
</tr>
</tbody>
</table>

Table 2: Example semantic relation clusters produced by our approach. For each cluster, we list the top paths in it, and each is followed by “:number”, indicating its sense obtained from sense disambiguation. They are ranked by the number of entity pairs they take. The column on the left shows sense of each relation. They are added manually by looking at the sense numbers associated with each path.
Example of visualization from Joseph Turian
Automatic vs. manual evaluation

- **Automatic evaluation**
  - Typically: compare system outputs to some “gold standard”
  - Pro: cheap, fast
  - Pro: objective, reproducible
  - Con: may not reflect end-user quality
  - Especially useful during development (formative evaluation)

- **Manual evaluation**
  - Generate system outputs, have humans assess them
  - Pro: directly assesses real-world utility
  - Con: expensive, slow
  - Con: subjective, inconsistent
  - Most useful in final assessment (summative evaluation)
Automatic evaluation

- Automatic evaluation against human-annotated data
  - But human-annotated data is not available for many tasks
  - Even when it is, quantities are often rather limited

- Automatic evaluation against synthetic data
  - Example: pseudowords (*bananadoor*) in WSD
  - Example: cloze (completion) experiments
    - Chambers & Jurafsky 2008; Busch, Colgrove, & Neidert 2012
  - Pro: virtually infinite quantities of data
  - Con: lack of realism

With a pile of browning *bananadoors*, I...
... like a *bananadoor* to another world...
... highland *bananadoors* are a vital crop...
... how to construct a sliding *bananadoor*.

<table>
<thead>
<tr>
<th>Known events: (pleaded subj), (admits subj), (convicted obj)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Likely Events:</td>
</tr>
<tr>
<td>sentenced obj</td>
</tr>
<tr>
<td>paroled obj</td>
</tr>
<tr>
<td>fired obj</td>
</tr>
</tbody>
</table>
Manual evaluation

- Generate system outputs, have humans evaluate them
- Pros: direct assessment of real-world utility
- Cons: expensive, slow, subjective, inconsistent
- But sometimes unavoidable! (Why?)
- Example: Banko et al. 2008
Intrinsic vs. extrinsic evaluation

- **Intrinsic (\textit{in vitro}, task-independent) evaluation**
  - Compare system outputs to some ground truth or gold standard

- **Extrinsic (\textit{in vivo}, task-based, end-to-end) evaluation**
  - Evaluate impact on performance of a larger system of which your model is a component
  - Pushes the problem back — need way to evaluate larger system
  - Pro: a more direct assessment of “real-world” quality
  - Con: often very cumbersome and time-consuming
  - Con: real gains may not be reflected in extrinsic evaluation

- **Example from automatic summarization**
  - Intrinsic: do summaries resemble human-generated summaries?
  - Extrinsic: do summaries help humans gather facts quicker?
Formative vs. summative evaluation

*When the cook tastes the soup, that’s formative; when the customer tastes the soup, that’s summative.*

- Formative evaluation: guiding further investigations
  - Typically: lightweight, automatic, intrinsic
  - Compare design option A to option B
  - Tune parameters: smoothing, weighting, learning rate

- Summative evaluation: reporting results
  - Compare your approach to previous approaches
  - Compare different variants of your approach
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The train/test split

- Evaluations on training data overestimate real performance!
  - Need to test model’s ability to generalize, not just memorize
  - But testing on training data can still be useful — how?

- So, sequester test data, use only for summative evaluation
  - Typically, set aside 10% or 20% of all data for final test set
  - If you’re using a standard dataset, the split is often predefined
  - Don’t evaluate on it until the very end! Don’t peek!

- Beware of subtle ways that test data can get tainted
  - Using same test data in repeated experiments
  - “Community overfitting”, e.g. on PTB parsing
  - E.g., matching items to users: partition on users, not matches
Development data

● Also known as “devtest” or “validation” data

● Used as test data during formative evaluations
  ○ Keep real test data pure until summative evaluation

● Useful for selecting (discrete) design options
  ○ Which categories of features to activate
  ○ Choice of classification (or clustering) algorithm
  ○ VSMs: choice of distance metric, normalization method, ...

● Useful for tuning (continuous) hyperparameters
  ○ Smoothing / regularization parameters
  ○ Combination weights in ensemble systems
  ○ Learning rates, search parameters
10-fold cross-validation (10CV)

<table>
<thead>
<tr>
<th></th>
<th>min</th>
<th>max</th>
<th>median</th>
<th>mean</th>
<th>stddev</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75.50</td>
<td>84.40</td>
<td>81.05</td>
<td>80.80</td>
<td>2.58</td>
</tr>
</tbody>
</table>
k-fold cross-validation

● Pros
  ○ Make better use of limited data
  ○ Less vulnerable to quirks of train/test split
  ○ Can estimate variance (etc.) of results
  ○ Enables crude assessment of statistical significance

● Cons
  ○ Slower (in proportion to k)
  ○ Doesn’t keep test data “pure” (if used in development)

● LOOCV = leave-one-out cross-validation
  ○ Increase k to the limit: the total number of instances
  ○ Magnifies both pros and cons
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- Project set-up & development
- Evaluation
- Dataset management
- Evaluation metrics
- Comparative evaluations
- Other aspects of evaluation
- Conclusion
Evaluation metrics

- An evaluation metric is a function: $model \times data \rightarrow \mathbb{R}$
- Can involve both manual and automatic elements
- Can serve as an objective function during development
  - For formative evaluations, identify *one* metric as primary
  - Known as “figure of merit”
  - Use it to guide design choices, tune hyperparameters
- You may use standard metrics, or design your own
  - Using standard metrics facilitates comparisons to prior work
  - But new problems may require new evaluation metrics
  - Either way, have good *reasons* for your choice
Example: evaluation metrics

Evaluation metrics are the *columns* of your main results table:

<table>
<thead>
<tr>
<th>System</th>
<th>Prec.</th>
<th>Rec.</th>
<th>F-0.5</th>
<th>MCC</th>
<th>Prec.</th>
<th>Rec.</th>
<th>F-0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rel-LDA/300</td>
<td>0.593</td>
<td>0.077</td>
<td>0.254</td>
<td>0.191</td>
<td>0.558</td>
<td>0.183</td>
<td>0.396</td>
</tr>
<tr>
<td>Rel-LDA/1000</td>
<td>0.638</td>
<td>0.061</td>
<td>0.220</td>
<td>0.177</td>
<td>0.626</td>
<td>0.160</td>
<td>0.396</td>
</tr>
<tr>
<td>HAC</td>
<td>0.567</td>
<td>0.152</td>
<td>0.367</td>
<td>0.261</td>
<td>0.523</td>
<td>0.248</td>
<td>0.428</td>
</tr>
<tr>
<td>Local</td>
<td>0.625</td>
<td>0.136</td>
<td>0.364</td>
<td>0.264</td>
<td>0.626</td>
<td>0.225</td>
<td>0.462</td>
</tr>
<tr>
<td>Local+Type</td>
<td>0.718</td>
<td>0.115</td>
<td>0.350</td>
<td>0.265</td>
<td><strong>0.704</strong></td>
<td>0.201</td>
<td>0.469</td>
</tr>
<tr>
<td>Our Approach</td>
<td><strong>0.736</strong></td>
<td><strong>0.156</strong></td>
<td><strong>0.422</strong></td>
<td><strong>0.314</strong></td>
<td>0.677</td>
<td>0.233</td>
<td><strong>0.490</strong></td>
</tr>
<tr>
<td>Our Approach+Type</td>
<td>0.682</td>
<td>0.110</td>
<td>0.334</td>
<td>0.250</td>
<td>0.687</td>
<td>0.199</td>
<td>0.460</td>
</tr>
</tbody>
</table>

from Yao et al. 2012
Evaluation metrics for classification

- Contingency tables & confusion matrices
- Accuracy
- Precision & recall
- F-measure
- AUC (area under ROC curve)
- Sensitivity & specificity
- PPV & NPV (positive/negative predictive value)
- MCC (Matthews correlation coefficient)
Contingency tables

- In binary classification, each instance has actual label ("gold")
- The model assigns to each instance a predicted label ("guess")
- A pair of labels [actual, predicted] determines an outcome
  - E.g., [actual:false, predicted:true] → false positive (FP)
- The contingency table counts the outcomes
- Forms basis of many evaluation metrics: accuracy, P/R, MCC, ...

<table>
<thead>
<tr>
<th></th>
<th>false</th>
<th>true</th>
</tr>
</thead>
<tbody>
<tr>
<td>gold</td>
<td></td>
<td></td>
</tr>
<tr>
<td>false</td>
<td>TN</td>
<td>FP</td>
</tr>
<tr>
<td></td>
<td>true negative</td>
<td>false positive</td>
</tr>
<tr>
<td>true</td>
<td>FN</td>
<td>TP</td>
</tr>
<tr>
<td></td>
<td>false negative</td>
<td>true positive</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>false</th>
<th>true</th>
</tr>
</thead>
<tbody>
<tr>
<td>gold</td>
<td></td>
<td></td>
</tr>
<tr>
<td>false</td>
<td>51</td>
<td>9</td>
</tr>
<tr>
<td>true</td>
<td>4</td>
<td>36</td>
</tr>
</tbody>
</table>

69
Confusion matrices

- Generalizes the contingency table to multiclass classification
- Correct predictions lie on the main diagonal
- Large off-diagonal counts reveal interesting “confusions”

<table>
<thead>
<tr>
<th></th>
<th>Y</th>
<th>N</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>gold</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>75</td>
<td>27</td>
<td>81</td>
</tr>
<tr>
<td>N</td>
<td>7</td>
<td>27</td>
<td>81</td>
</tr>
<tr>
<td>U</td>
<td>7</td>
<td>27</td>
<td>81</td>
</tr>
</tbody>
</table>

from MacCartney & Manning 2008
Accuracy

- Accuracy: percent correct among all instances
- The most basic and ubiquitous evaluation metric
- But, it has serious limitations (what?)

Accuracy = \frac{86 + 3}{100} = 89.0\%

Accuracy = \frac{67 + 16 + 46}{183} = 70.5\%
Precision & recall

- Precision: % correct among items where guess=true
- Recall: % correct among items where gold=true
- Preferred to accuracy, especially for highly-skewed problems

\[
\text{recall} = \frac{3}{12} = 25.0\%
\]

\[
\text{precision} = \frac{3}{5} = 60.0\%
\]
It’s helpful to have a single measure which combines P and R

But we don’t use the arithmetic mean of P and R (why not?)

Rather, we use the harmonic mean: $F_1 = \frac{2PR}{P + R}$

<table>
<thead>
<tr>
<th>gold</th>
<th>guess</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>T</td>
<td>9</td>
</tr>
<tr>
<td>95</td>
<td>5</td>
</tr>
</tbody>
</table>

recall = $\frac{3}{12} = 25.0\%$

precision = $\frac{3}{5} = 60.0\%$

$F_1 = 35.3\%$
Why use harmonic mean?

Figure 8.1  Graph comparing the harmonic mean to other means. The graph shows a slice through the calculation of various means of precision and recall for the fixed recall value of 70%. The harmonic mean is always less than either the arithmetic or geometric mean, and often quite close to the minimum of the two numbers. When the precision is also 70%, all the measures coincide.

from Manning et al. 2009
F-measure

- Some applications need more precision; others, more recall
- $F_\beta$ is the *weighted* harmonic mean of $P$ and $R$
- $F_\beta = \frac{(1 + \beta^2)PR}{\beta^2P + R}$

<table>
<thead>
<tr>
<th>recall</th>
<th>0.10</th>
<th>0.30</th>
<th>0.60</th>
<th>0.90</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>0.10</td>
<td>0.21</td>
<td>0.30</td>
<td>0.35</td>
</tr>
<tr>
<td>0.10</td>
<td>0.10</td>
<td>0.15</td>
<td>0.17</td>
<td>0.18</td>
</tr>
<tr>
<td>0.10</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>0.30</td>
<td>0.12</td>
<td>0.30</td>
<td>0.50</td>
<td>0.64</td>
</tr>
<tr>
<td>0.15</td>
<td>0.30</td>
<td>0.40</td>
<td>0.60</td>
<td>0.82</td>
</tr>
<tr>
<td>0.21</td>
<td>0.30</td>
<td>0.33</td>
<td>0.60</td>
<td>0.72</td>
</tr>
<tr>
<td>0.60</td>
<td>0.12</td>
<td>0.33</td>
<td>0.64</td>
<td>0.90</td>
</tr>
<tr>
<td>0.17</td>
<td>0.30</td>
<td>0.45</td>
<td>0.72</td>
<td>0.90</td>
</tr>
<tr>
<td>0.30</td>
<td>0.12</td>
<td>0.64</td>
<td>0.82</td>
<td>0.90</td>
</tr>
<tr>
<td>0.35</td>
<td>0.35</td>
<td>0.64</td>
<td>0.82</td>
<td>0.90</td>
</tr>
<tr>
<td>0.90</td>
<td>0.35</td>
<td>0.64</td>
<td>0.82</td>
<td>0.90</td>
</tr>
</tbody>
</table>

- $\beta = 2.0$ (favor recall)
- $\beta = 1.0$ (neutral)
- $\beta = 0.5$ (favor precision)
F-measure

- Some applications need more precision; others, more recall
- $F_\beta$ is the *weighted* harmonic mean of $P$ and $R$
- $F_\beta = (1 + \beta^2)PR / (\beta^2P + R)$

$\beta = 0.5$ (favor precision)  $\beta = 1.0$ (neutral)  $\beta = 2.0$ (favor recall)
Precision vs. recall

- Typically, there’s a trade-off between precision and recall
  - High threshold → high precision, low recall
  - Low threshold → low precision, high recall

- P/R curve facilitates making an explicit choice on trade-off

- Always put recall on x-axis, and expect noise on left (why?)

from Manning et al. 2009
Precision/recall curve example

from Snow et al. 2005
Precision/recall curve example

from Mintz et al. 2009
ROC curves and AUC

- ROC curve = receiver operating characteristic curve
  - An alternative to P/R curve used in other fields (esp. EE)

- AUC = area under (ROC) curve
  - Like F1, a single metric which promotes both P and R
  - But doesn’t permit specifying tradeoff, and generally unreliable

from Davis & Goadrich 2006
Sensitivity & specificity

- Sensitivity & specificity look at % correct by actual label
  - Sensitivity: % correct among items where gold=true (= recall)
  - Specificity: % correct among items where gold=false

- An alternative to precision & recall
  - More common in statistics literature

**Example:**

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>gold F</td>
<td>86</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>gold T</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

- Specificity = \( \frac{86}{88} = 97.7\% \)
- Sensitivity = \( \frac{3}{12} = 25.0\% \)
**PPV & NPV**

- PPV & NPV look at % correct by **predicted** label
  - PPV: % correct among items where guess=true (= precision)
  - NPV: % correct among items where guess=false

- An alternative to precision & recall
  - More common in statistics literature

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>86</td>
<td>2</td>
</tr>
<tr>
<td>T</td>
<td>9</td>
<td>3</td>
</tr>
</tbody>
</table>

NPV: \[
\frac{86}{95} = 90.5\%
\]

PPV: \[
\frac{3}{5} = 60.0\%
\]
Matthews correlation coefficient (MCC)

- Correlation between actual & predicted classifications
- Random guessing yields 0; perfect prediction yields 1

\[
MCC = \frac{TP \times TN - FP \times FN}{\sqrt{(TP + FP)(TP + FN)(TN + FP)(TN + FN)}}
\]

<table>
<thead>
<tr>
<th>Precision</th>
<th>Recall</th>
<th>MCC</th>
<th>0.05</th>
<th>0.35</th>
<th>0.65</th>
<th>0.95</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>-0.90</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.35</td>
<td>-0.11</td>
<td>-0.30</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.65</td>
<td>0.08</td>
<td>0.22</td>
<td>0.30</td>
<td>0.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.95</td>
<td>0.21</td>
<td>0.55</td>
<td>0.74</td>
<td>0.90</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Precision</th>
<th>Recall</th>
<th>MCC</th>
<th>0.05</th>
<th>0.35</th>
<th>0.65</th>
<th>0.95</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>-0.06</td>
<td>-0.15</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.35</td>
<td>0.10</td>
<td>0.28</td>
<td>0.38</td>
<td>0.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.65</td>
<td>0.17</td>
<td>0.45</td>
<td>0.61</td>
<td>0.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.95</td>
<td>0.22</td>
<td>0.57</td>
<td>0.78</td>
<td>0.94</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

with prevalence = 0.10
Recap: metrics for classifiers

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>accuracy</td>
<td>proportion of all items predicted correctly</td>
</tr>
<tr>
<td>error</td>
<td>proportion of all items predicted incorrectly</td>
</tr>
<tr>
<td>sensitivity</td>
<td>accuracy over items actually true</td>
</tr>
<tr>
<td>specificity</td>
<td>accuracy over items actually false</td>
</tr>
<tr>
<td>PPV</td>
<td>accuracy over items predicted true</td>
</tr>
<tr>
<td>NPV</td>
<td>accuracy over items predicted false</td>
</tr>
<tr>
<td>precision</td>
<td>accuracy over items predicted true</td>
</tr>
<tr>
<td>recall</td>
<td>accuracy over items actually true</td>
</tr>
<tr>
<td>F1</td>
<td>harmonic mean of precision and recall</td>
</tr>
<tr>
<td>MCC</td>
<td>correlation between actual &amp; predicted classifications</td>
</tr>
</tbody>
</table>
Recap: metrics for classifiers

<table>
<thead>
<tr>
<th>gold</th>
<th>guess</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>T</td>
</tr>
<tr>
<td>F</td>
<td>#tn</td>
</tr>
<tr>
<td>T</td>
<td>#fn</td>
</tr>
</tbody>
</table>

- Specificity
- Sensitivity = recall
- Accuracy
- NPV
- PPV = precision
- $F_\beta$
Multiclass classification

- Precision, recall, $F_1$, MCC, ... are for binary classification

- For multiclass classification, compute these stats *per class*
  - For each class, project into binary classification problem
  - TRUE = this class; FALSE = all other classes

- Then average the results
  - Macro-averaging: equal weight for each class
  - Micro-averaging: equal weight for each instance

- See worked-out example on next slide
Multiclass classification

<table>
<thead>
<tr>
<th>gold</th>
<th>guess</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>67</td>
</tr>
<tr>
<td>N</td>
<td>1</td>
</tr>
<tr>
<td>U</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>class</th>
<th>precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>67/75     = 89.3%</td>
</tr>
<tr>
<td>N</td>
<td>16/27     = 59.3%</td>
</tr>
<tr>
<td>U</td>
<td>46/81     = 56.8%</td>
</tr>
</tbody>
</table>

Macro-averaged precision:
\[ \frac{89.3 + 59.3 + 56.8}{3} = 68.5\% \]

Micro-averaged precision:
\[ \frac{75 \cdot 89.3 + 27 \cdot 59.3 + 81 \cdot 56.8}{183} = 70.5\% \]
Evaluation metrics for retrieval

- Retrieval & recommendation problems
  - Very large space of possible outputs, many good answers
  - But outputs are simple (URLs, object ids), not structured

- Can be formulated as binary classification (of relevance)

- Problem: can’t identify all positive items in advance
  - So, can’t assess recall — look at coverage instead
  - Even precision is tricky, may require semi-manual process

- Evaluation metrics for ranked retrieval
  - Precision@k
  - Mean average precision (MAP)
  - Discounted cumulative gain
Evaluation metrics for complex outputs

- If outputs are numerous *and* complex, evaluation is trickier
  - Text (e.g., automatic summaries)
  - Tree structures (e.g., syntactic or semantic parses)
  - Grid structure (e.g., alignments)

- System outputs are unlikely to match gold standard exactly

- One option: manual eval — but slow, costly, subjective

- Another option: *approximate* comparison to gold standard
  - Give partial credit for partial matches
  - Text: n-gram overlap (ROUGE)
  - Tree structures: precision & recall over subtrees
  - Grid structures: precision & recall over pairs
Evaluation metrics for clustering

- **Pairwise metrics** (Hatzivassiloglou & McKeown 1993)
  - Reformulate as binary classification over *pairs* of items
  - Compute & report precision, recall, F1, MCC, ... as desired

- **B³ metrics** (Bagga & Baldwin 1998)
  - Reformulate as a set of binary classification tasks, one per item
  - For each item, predict whether other items are in same cluster
  - Average per-item results over items (micro) or clusters (macro)

- **Intrusion tasks**
  - In predicted clusters, replace one item with random “intruder”
  - Measure human raters’ ability to identify intruder

- See **Homework 2, Yao et al. 2012**
Other evaluation metrics

- **Regression problems**
  - When the output is a real number
  - *Pearson’s R*
  - *Mean squared error*

- **Ranking problems**
  - When the output is a rank
  - *Spearman’s rho*
  - *Kendall’s tau*
  - *Mean reciprocal rank*
Agenda

● Overview
● Lit review
● Data sources
● Project set-up & development
● Evaluation
● Dataset management
● Evaluation metrics
● Comparative evaluations
● Other aspects of evaluation
● Conclusion
Comparative evaluation

- Say your model scores 77% on your chosen evaluation metric
- *Is that good? Is it bad?*
- You (& your readers) can’t know unless you make comparisons
  - Baselines
  - Upper bounds
  - Previous work
  - Different variants of your model
- Comparisons are the *rows* of your main results table
  - Evaluation metrics are the columns
- Comparisons demand statistical significance testing!
Baselines

- 77% doesn’t look so good if a blindfolded mule can get 73%
- Results without baseline comparisons are meaningless
- Weak baselines: performance of zero-knowledge systems
  - Systems which use no information about the specific instance
  - Example: random guessing models
  - Example: most-frequent class (MFC) models
- Strong baselines: performance of easily-implemented systems
  - Systems which can be implemented in an hour or less
  - WSD example: Lesk algorithm
  - RTE example: bag-of-words
## Baselines example

![Baseline comparison table](image)

<table>
<thead>
<tr>
<th>word</th>
<th>#s</th>
<th>#ex</th>
<th>baselines</th>
<th>word sense disambig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>argument</td>
<td>2</td>
<td>114</td>
<td>70.17%</td>
<td>89.47%</td>
</tr>
<tr>
<td>arm</td>
<td>3</td>
<td>291</td>
<td>61.85%</td>
<td>84.87%</td>
</tr>
<tr>
<td>atmosphere</td>
<td>3</td>
<td>773</td>
<td>54.33%</td>
<td>71.66%</td>
</tr>
<tr>
<td>bank</td>
<td>3</td>
<td>1074</td>
<td>97.20%</td>
<td>97.20%</td>
</tr>
<tr>
<td>bar</td>
<td>10</td>
<td>1108</td>
<td>47.38%</td>
<td>83.12%</td>
</tr>
<tr>
<td>chair</td>
<td>3</td>
<td>194</td>
<td>67.57%</td>
<td>80.92%</td>
</tr>
<tr>
<td>channel</td>
<td>5</td>
<td>366</td>
<td>51.09%</td>
<td>71.85%</td>
</tr>
<tr>
<td>circuit</td>
<td>4</td>
<td>327</td>
<td>85.32%</td>
<td>87.15%</td>
</tr>
<tr>
<td>degree</td>
<td>7</td>
<td>849</td>
<td>58.77%</td>
<td>85.98%</td>
</tr>
<tr>
<td>difference</td>
<td>2</td>
<td>24</td>
<td>75.00%</td>
<td>75.00%</td>
</tr>
<tr>
<td>disc</td>
<td>3</td>
<td>73</td>
<td>52.05%</td>
<td>71.23%</td>
</tr>
</tbody>
</table>

From Mihalcea 2007
Example: strong baselines

<table>
<thead>
<tr>
<th>System</th>
<th>Prec.</th>
<th>Rec.</th>
<th>F-0.5</th>
<th>MCC</th>
<th>Prec.</th>
<th>Rec.</th>
<th>F-0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rel-LDA/300</td>
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<td>0.077</td>
<td>0.254</td>
<td>0.191</td>
<td>0.558</td>
<td>0.183</td>
<td>0.396</td>
</tr>
<tr>
<td>Rel-LDA/1000</td>
<td>0.638</td>
<td>0.061</td>
<td>0.220</td>
<td>0.177</td>
<td>0.626</td>
<td>0.160</td>
<td>0.396</td>
</tr>
<tr>
<td>HAC</td>
<td>0.567</td>
<td>0.152</td>
<td>0.367</td>
<td>0.261</td>
<td>0.523</td>
<td>0.248</td>
<td>0.428</td>
</tr>
<tr>
<td>Local</td>
<td>0.625</td>
<td>0.136</td>
<td>0.364</td>
<td>0.264</td>
<td>0.626</td>
<td>0.225</td>
<td>0.462</td>
</tr>
<tr>
<td>Local+Type</td>
<td>0.718</td>
<td>0.115</td>
<td>0.350</td>
<td>0.265</td>
<td>0.704</td>
<td>0.201</td>
<td>0.469</td>
</tr>
<tr>
<td>Our Approach</td>
<td>0.736</td>
<td>0.156</td>
<td>0.422</td>
<td>0.314</td>
<td>0.677</td>
<td>0.233</td>
<td>0.490</td>
</tr>
<tr>
<td>Our Approach+Type</td>
<td>0.682</td>
<td>0.110</td>
<td>0.334</td>
<td>0.250</td>
<td>0.687</td>
<td>0.199</td>
<td>0.460</td>
</tr>
</tbody>
</table>

from Yao et al. 2012
Upper bounds

- 77% doesn’t look so bad if a human expert gets only 83%
- *Plausible, defendible* upper bounds can flatter your results
- Human performance is often taken as an upper bound
  - Or inter-annotator agreement (for subjective labels)
  - (BTW, if you annotate your own data, report the [kappa statistic](#))
  - If humans agree on only 83%, how can machines ever do better?
  - But in some tasks, machines outperform humans! ([Ott et al. 2011](#))
- Also useful: oracle experiments
  - Supply gold output for some component of pipeline (e.g., parser)
  - Let algorithm access some information it wouldn’t usually have
  - Can illuminate the system’s operation, strengths & weaknesses
Comparisons to previous work

- Desirable, but not always possible — you may be a pioneer!

- Easy: same problem, same test data, same evaluation metric
  - Just copy results from previous work into your results table
  - The norm in tasks with standard data sets: ACE, Geo880, RTE, ...

- Harder: same problem, but different data, or different metric
  - Maybe you can obtain their code, and evaluate in your setup?
  - Maybe you can reimplement their system? Or an approximation?

- Hardest: new problem, new data set
  - Example: double entendre identification (Kiddon & Brun 2011)
  - Make your data set publicly available!
  - Let future researchers can compare to you
Different variants of your model

- Helps to shed light your model’s strengths & weaknesses

- Lots of elements can be varied
  - Quantity, corpus, or genre of training data
  - Active feature categories
  - Classifier type or clustering algorithm
  - VSMs: distance metric, normalization method, ...
  - Smoothing / regularization parameters
Relative improvements

- It may be preferable to express improvements in *relative* terms
  - Say baseline was 60%, and your model achieved 75%
  - Absolute gain: 15%
  - Relative improvement: 25%
  - Relative error reduction: 37.5%

- Can be more informative (as well as more flattering!)
  - Previous work: 92.1%
  - Your model: 92.9%
  - Absolute gain: 0.8% (yawn)
  - Relative error reduction: 10.1% (wow!)
Statistical significance testing

- Pet peeve: small gains reported as fact w/o significance testing
  - “... outperforms previous approaches ...”
  - “... demonstrates that word features help ...”

- How likely is the gain you observed, under the null hypothesis?
  - Namely: model is no better than baseline, and gain is due to chance

- Crude solution: estimate variance using 10CV, or “the bootstrap”

- Analytic methods: McNemar’s paired test, many others ...

- Monte Carlo methods: approximate randomization
  - Easy to implement, reliable, principled
  - Highly recommended reading: http://masanjin.net/sigtest.pdf
Significant skepticism

Lately there’s been some healthy skepticism about the value of p-values. For example:

http://www.nature.com/news/scientific-method-statistical-errors-1.14700

Lesson: $p < 0.05$ may not be a reliable indicator of a truly significant result.

But $p > 0.05$ still means you haven’t proven s---.

And you should still do significance testing!
Still not significant

If the result ain’t significant, just admit it!
No weasel words!

<table>
<thead>
<tr>
<th>(barely) not statistically significant (p=0.052)</th>
<th>just lacked significance (p=0.053)</th>
<th>slightly significant (p=0.09)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a borderline significant trend (p=0.09)</td>
<td>just marginally significant (p=0.0562)</td>
<td>somewhat marginally significant (p=0.055)</td>
</tr>
<tr>
<td>a certain trend toward significance (p=0.08)</td>
<td>just missing significance (p=0.07)</td>
<td>somewhat short of significance (p=0.07)</td>
</tr>
<tr>
<td>a clear tendency to significance (p=0.052)</td>
<td>just on the verge of significance (p=0.06)</td>
<td>somewhat significant (p=0.23)</td>
</tr>
<tr>
<td>a clear, strong trend (p=0.09)</td>
<td>just outside levels of significance (p&lt;0.08)</td>
<td>strong trend toward significance (p=0.08)</td>
</tr>
<tr>
<td>a decreasing trend (p=0.09)</td>
<td>just outside the bounds of significance (p=0.06)</td>
<td>sufficiently close to significance (p=0.07)</td>
</tr>
<tr>
<td>a definite trend (p=0.08)</td>
<td>just outside the level of significance (p=0.0683)</td>
<td>suggestive of a significant trend (p=0.08)</td>
</tr>
<tr>
<td>a distinct trend toward significance (p=0.07)</td>
<td>just outside the limits of significance (p=0.06)</td>
<td>suggestive of statistical significance (p=0.06)</td>
</tr>
<tr>
<td>a favourable trend (p=0.09)</td>
<td>just short of significance (p=0.07)</td>
<td>suggestively significant (p=0.064)</td>
</tr>
<tr>
<td>a little significant (p&lt;0.1)</td>
<td>just shy of significance (p=0.053)</td>
<td>tantalisingly close to significance (p=0.104)</td>
</tr>
<tr>
<td>a margin at the edge of significance (p=0.0608)</td>
<td>just tendentially significant (p=0.056)</td>
<td>technically not significant (p=0.06)</td>
</tr>
<tr>
<td>a marginal trend (p=0.09)</td>
<td>leaning towards significance (p=0.15)</td>
<td>teetering on the brink of significance (p=0.06)</td>
</tr>
<tr>
<td>a marginal trend toward significance (p=0.052)</td>
<td>leaning towards statistical significance (p=0.06)</td>
<td>tended toward significance (p=0.13)</td>
</tr>
<tr>
<td>a marked trend (p=0.07)</td>
<td>likely to be significant (p=0.054)</td>
<td>tentatively significant (p=0.107)</td>
</tr>
<tr>
<td>a mild trend (p=0.09)</td>
<td>loosely significant (p=0.10)</td>
<td>trend in a significant direction (p=0.09)</td>
</tr>
<tr>
<td>a near-significant trend (p=0.07)</td>
<td>marginal significance (p=0.07)</td>
<td>trending towards significant (p=0.099)</td>
</tr>
<tr>
<td>a nonsignificant trend (p&lt;0.1)</td>
<td>marginally and negatively significant (p=0.08)</td>
<td>vaguely significant (p&gt;0.2)</td>
</tr>
<tr>
<td>a notable trend (p&lt;0.1)</td>
<td>marginally insignificant (p=0.08)</td>
<td>verging on significance (p=0.056)</td>
</tr>
<tr>
<td>a numerical increasing trend (p=0.09)</td>
<td>marginally nonsignificant (p=0.096)</td>
<td>very narrowly missed significance (p=0.06)</td>
</tr>
<tr>
<td>a numerical trend (p=0.09)</td>
<td>marginally outside the level of significance</td>
<td>very nearly significant (p=0.0656)</td>
</tr>
<tr>
<td>a positive trend (p=0.09)</td>
<td>marginally significant (p=0.01)</td>
<td>very slightly non-significant (p=0.10)</td>
</tr>
<tr>
<td>a possible trend toward significance (p=0.052)</td>
<td>marginally significant tendency (p=0.08)</td>
<td>very slightly significant (p=0.1)</td>
</tr>
<tr>
<td>a pronounced trend (p=0.09)</td>
<td>marginally statistically significant (p=0.08)</td>
<td>virtually significant (p=0.059)</td>
</tr>
<tr>
<td>a reliable trend (p=0.058)</td>
<td>may not be significant (p=0.06)</td>
<td>weak significance (p=0.10)</td>
</tr>
<tr>
<td>a robust trend toward significance (p=0.0503)</td>
<td>medium level of significance (p=0.051)</td>
<td>weakly significant (p=0.11)</td>
</tr>
<tr>
<td>a significant trend (p=0.09)</td>
<td>mildly significant (p=0.07)</td>
<td>weakly statistically significant (p=0.0557)</td>
</tr>
<tr>
<td></td>
<td>moderately significant (p&gt;0.11)</td>
<td>well-nigh significant (p=0.11)</td>
</tr>
</tbody>
</table>

http://mchankins.wordpress.com/2013/04/21/still-not-significant-2/
Agenda

- Overview
- Lit review
- Data sources
- Project set-up & development
- Evaluation
- Dataset management
- Evaluation metrics
- Comparative evaluations
- Other aspects of evaluation
- Conclusion
Learning curve example

Figure IV. Just a few training examples do surprisingly well. The horizontal axis shows the number of examples used in training while the vertical scale shows the mean percent correct in six disambiguations. The performance increases rapidly for the first few examples, and seems to have reached a maximum by 50 or 60 examples.

from Gale, Church, & Yarowsky 1992
Learning curve example

from Ng & Zelle 1997
Learning curve example

from Mihalcea 2007
Learning curves

- Plot evaluation metric as function of amount of training data
- May include multiple variants of model (e.g. classifier types)
- Provides insight into learning properties of model
- Pop quiz: what does it mean if...
  - ... the curve is flat and never climbs?
  - ... the curve climbs and doesn’t ever level off?
  - ... the curve climbs at first, but levels off quite soon?
Feature analysis

- **Goal:** understand which features are most informative
- **Easy, but potentially misleading: list high-weight features**
  - Implicitly assumes that features are independent
- **Per-feature statistical measures**
  - E.g., chi-square, information gain
  - Again, ignores potential feature interactions
- **Ablation (or addition) tests**
  - Progressively knock out (or add) (categories of) features
  - Do comparative evaluations at each step — often expensive!
- **L1 regularization, Lasso, & other feature selection algorithms**
  - Which features are selected? What are the regularization paths?
Example: high-weight features

<table>
<thead>
<tr>
<th>Relation</th>
<th>Feature type</th>
<th>Left window</th>
<th>NE1</th>
<th>Middle</th>
<th>NE2</th>
<th>Right window</th>
</tr>
</thead>
<tbody>
<tr>
<td>/architecture/structure/architect</td>
<td>LEX (</td>
<td>designed</td>
<td>ORG</td>
<td>the designer of the</td>
<td>PER</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SYN</td>
<td></td>
<td></td>
<td>s novel</td>
<td>PER</td>
<td></td>
</tr>
<tr>
<td>/book/author/works_written</td>
<td>SYN</td>
<td>PER</td>
<td>ORG</td>
<td>by s novel</td>
<td>PER</td>
<td></td>
</tr>
<tr>
<td>/business/company/founders</td>
<td>LEX (</td>
<td></td>
<td>PER</td>
<td>co-founder</td>
<td>PER</td>
<td></td>
</tr>
<tr>
<td>/business/company/place.founded</td>
<td>LEX (</td>
<td></td>
<td>ORG</td>
<td>- based</td>
<td>LOC</td>
<td></td>
</tr>
<tr>
<td>/film/film/country</td>
<td>LEX</td>
<td>PER</td>
<td></td>
<td>released in</td>
<td>LOC</td>
<td></td>
</tr>
<tr>
<td>/geography/river/mouth</td>
<td>SYN</td>
<td>opened</td>
<td>ORG</td>
<td>which flows into the</td>
<td>LOC</td>
<td></td>
</tr>
<tr>
<td>/government/political/party/country</td>
<td>SYN</td>
<td>the</td>
<td>LOC</td>
<td>tribunary</td>
<td>LOC</td>
<td></td>
</tr>
<tr>
<td>/influence/influence_node/influenced</td>
<td>LEX (</td>
<td>candidate</td>
<td>ORG</td>
<td>politician of the</td>
<td>LOC</td>
<td></td>
</tr>
<tr>
<td>/language/human/language/region</td>
<td>SYN</td>
<td>of pen</td>
<td>PER</td>
<td>speaking areas of</td>
<td>LOC</td>
<td></td>
</tr>
<tr>
<td>/music/artist/origin</td>
<td>LEX (</td>
<td>is</td>
<td>ORG</td>
<td>based band</td>
<td>LOC</td>
<td></td>
</tr>
<tr>
<td>/people/deceased.person/place.of.death</td>
<td>LEX</td>
<td>hanged</td>
<td>PER</td>
<td>died</td>
<td>LOC</td>
<td></td>
</tr>
<tr>
<td>/people/person/nationality</td>
<td>LEX</td>
<td></td>
<td>PER</td>
<td>is a citizen of</td>
<td>LOC</td>
<td></td>
</tr>
<tr>
<td>/people/person/parents</td>
<td>LEX</td>
<td></td>
<td>PER</td>
<td>son of</td>
<td>PER</td>
<td></td>
</tr>
<tr>
<td>/people/person/place.of.birth</td>
<td>LEX (</td>
<td></td>
<td>PER</td>
<td>is the birthplace of</td>
<td>PER</td>
<td></td>
</tr>
<tr>
<td>/people/person/relation</td>
<td>LEX</td>
<td>convert</td>
<td>PER</td>
<td>embraced</td>
<td>LOC</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Examples of high-weight features for several relations. Key: SYN = syntactic feature; LEX = lexical feature; ▼ = reversed; NE# = named entity tag of entity.

from Mintz et al. 2009
Example: feature addition tests

<table>
<thead>
<tr>
<th>Features</th>
<th>P</th>
<th>R</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Words</td>
<td>69.2</td>
<td>23.7</td>
<td>35.3</td>
</tr>
<tr>
<td>+Entity Type</td>
<td>67.1</td>
<td>32.1</td>
<td>43.4</td>
</tr>
<tr>
<td>+Mention Level</td>
<td>67.1</td>
<td>33.0</td>
<td>44.2</td>
</tr>
<tr>
<td>+Overlap</td>
<td>57.4</td>
<td>40.9</td>
<td>47.8</td>
</tr>
<tr>
<td>+Chunking</td>
<td>61.5</td>
<td>46.5</td>
<td>53.0</td>
</tr>
<tr>
<td>+Dependency Tree</td>
<td>62.1</td>
<td>47.2</td>
<td>53.6</td>
</tr>
<tr>
<td>+Parse Tree</td>
<td>62.3</td>
<td>47.6</td>
<td>54.0</td>
</tr>
<tr>
<td>+Semantic Resources</td>
<td>63.1</td>
<td>49.5</td>
<td>55.5</td>
</tr>
</tbody>
</table>

Table 2: Contribution of different features over 43 relation subtypes in the test data

from Zhou et al. 2005
Visualizations

- Helpful in making multiple formal and informal comparisons, identify overlooked relationships
- t-SNE for 2d visualization of high-dimensional data: http://homepage.tudelft.nl/19j49/t-SNE.html
- Gephi: http://gephi.org/
- Visualization tools from Jeff Heer’s group: http://hci.stanford.edu/jheer/
Example: regularization paths

made using the \texttt{glmnet} package in R
Error analysis

- Analyze and categorize specific errors (on dev data, not test!)
- A form of qualitative evaluation — yet indispensable!

- During development (formative evaluation):
  - Examine individual mistakes, group into categories
  - Can be helpful to focus on FPs, FNs, common confusions
  - Brainstorm remedies for common categories of error
  - A key driver of iterative cycles of feature engineering

- In your report (summative evaluation):
  - Describe common categories of errors, exhibit specific examples
  - Aid the reader in understanding limitations of your approach
  - Highlight opportunities for future work
Error analysis example

4.3 Error Analysis

We also closely analyze the pairwise errors that we encounter when comparing against Freebase labels. Some errors arise because one instance can have multiple labels, as we explained in Section 4.1. One example is the following: Our approach predicts that (News Corporation, buy, MySpace) and (Dow Jones & Company, the parent of, The Wall Street Journal) are in one relation. In Freebase, one is labeled as “/organization/parent/child”, the other is labeled as “/book/newspaper_owner/newspapers_owned”. The latter is a sub-relation of the former. We can overcome this issue by introducing hierarchies in relation labels.

Some errors are caused by selecting the incorrect sense for an entity pair of a path. For instance, we put (Kenny Smith, who grew up in, Queens) and (Phil Jackson, return to, Los Angeles Lakers) into
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Don’t fear negative results

*Research is the process of going up alleys to see if they are blind.* — Marston Bates, American zoologist, 1906-1974

- Sometimes the results aren’t as good as you’d like
  - Sometimes you can’t show a statistically significant gain
  - Sometimes you can’t even beat the weak baseline 😞

- Your research work can still have value!
  - Especially if what you tried was a reasonable thing to try
  - Save future researchers from going up the same blind alleys
  - Worst case: error analysis is most valuable part of your paper

- Resist the temptation to optimize on test data
  - This is basically intellectual fraud
Plan for evaluation early

Evaluation should not be merely an afterthought; it must be an integral part of designing a research project.

You can’t aim if you don’t have a target; you can’t optimize if you don’t have an objective function.

First decide how to measure success; then pursue it relentlessly!

Whoa, dude, that’s some serious Yoda shit.
Game plan

- Form a team of 3 and choose a topic
- Survey previous work — lit review due May 6
- Identify data sources now
  - Ideally, find existing data suitable for your project
  - Otherwise, consider annotating or crowdsourcing
- Leverage off-the-shelf tools where possible
- Launch & iterate — “anytime” research process
- Plan for evaluation early!