Credit Networks

Ashish Goel, CS 261

Based on
https://arxiv.org/abs/1007.0515
http://dl.acm.org/citation.cfm?id=2722264

January 19, 2017

- Decentralized payment infrastructure introduced by [DeFigueiredo, Barr, 2005] and [Ghosh et. al., 2007]
- Do not need banks, common currency
- Models trust in networked interactions
- A robust "reputation system" for transaction oriented social networks

Barter and Currency

- Barter: If I need a goat from you, I had better have the blanket that you are looking for. Low liquidity.
- Centralized banks: Issue currencies, which are essentially IOUs from the bank. Very high liquidity; allows strangers to trade freely.
- Credit Networks: Bilateral exchange of IOUs among friends.

Illustration: Centralized Currency

Illustration: Centralized Currency

Illustration: Centralized Currency

Illustration: Centralized Currency

Illustration: Centralized Currency

10

Illustration: Centralized Currency

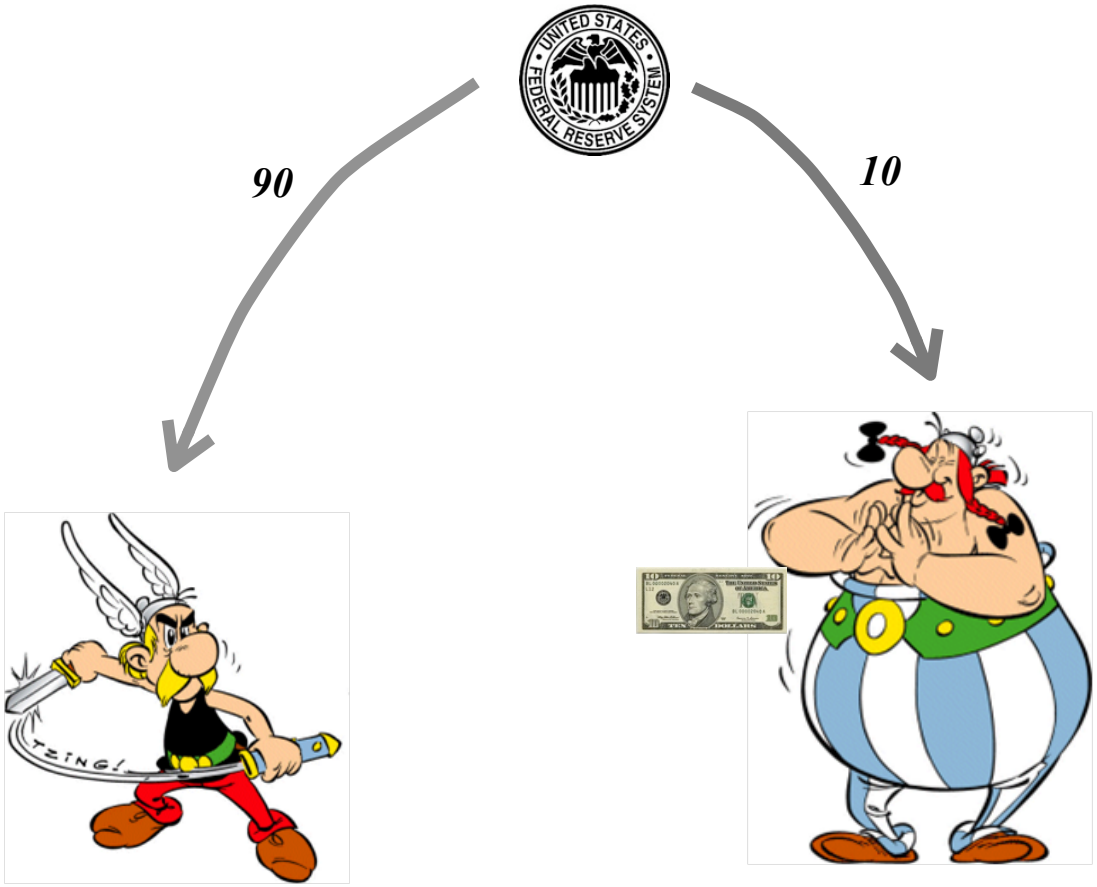


Illustration: Centralized Currency

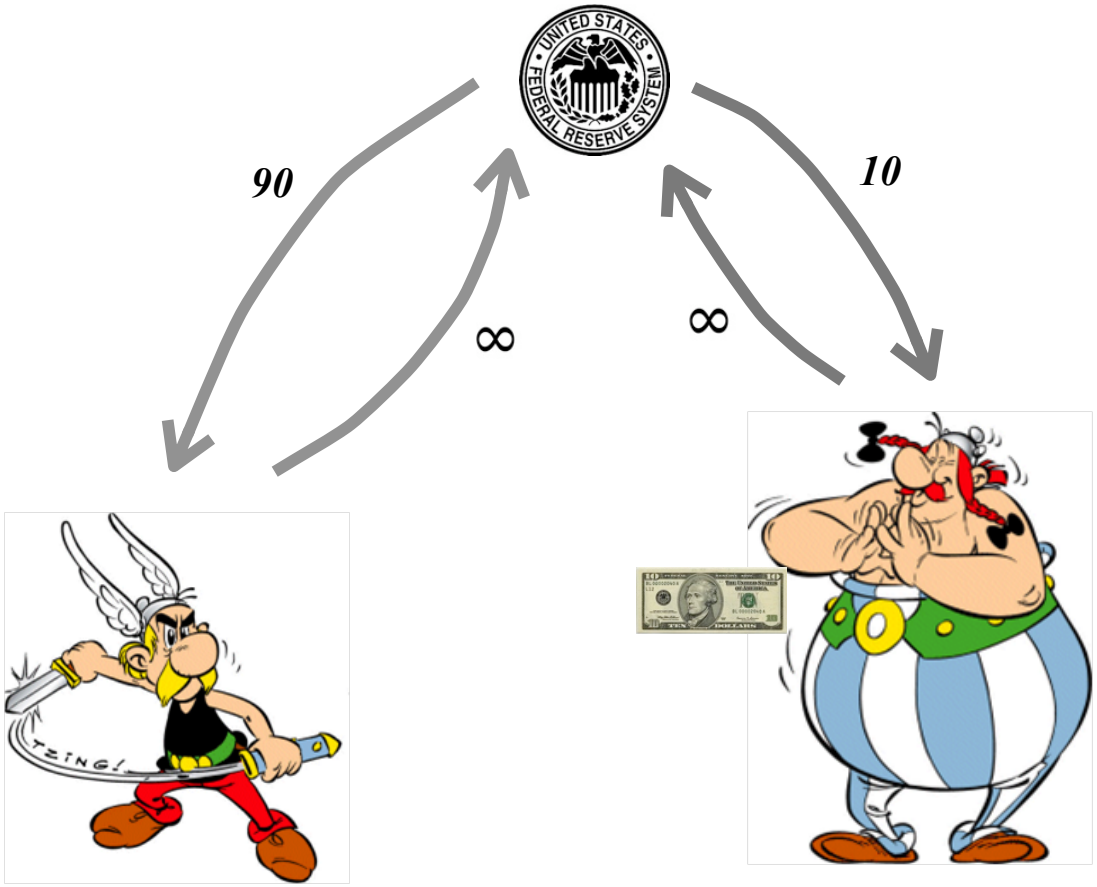


Illustration: Centralized Currency

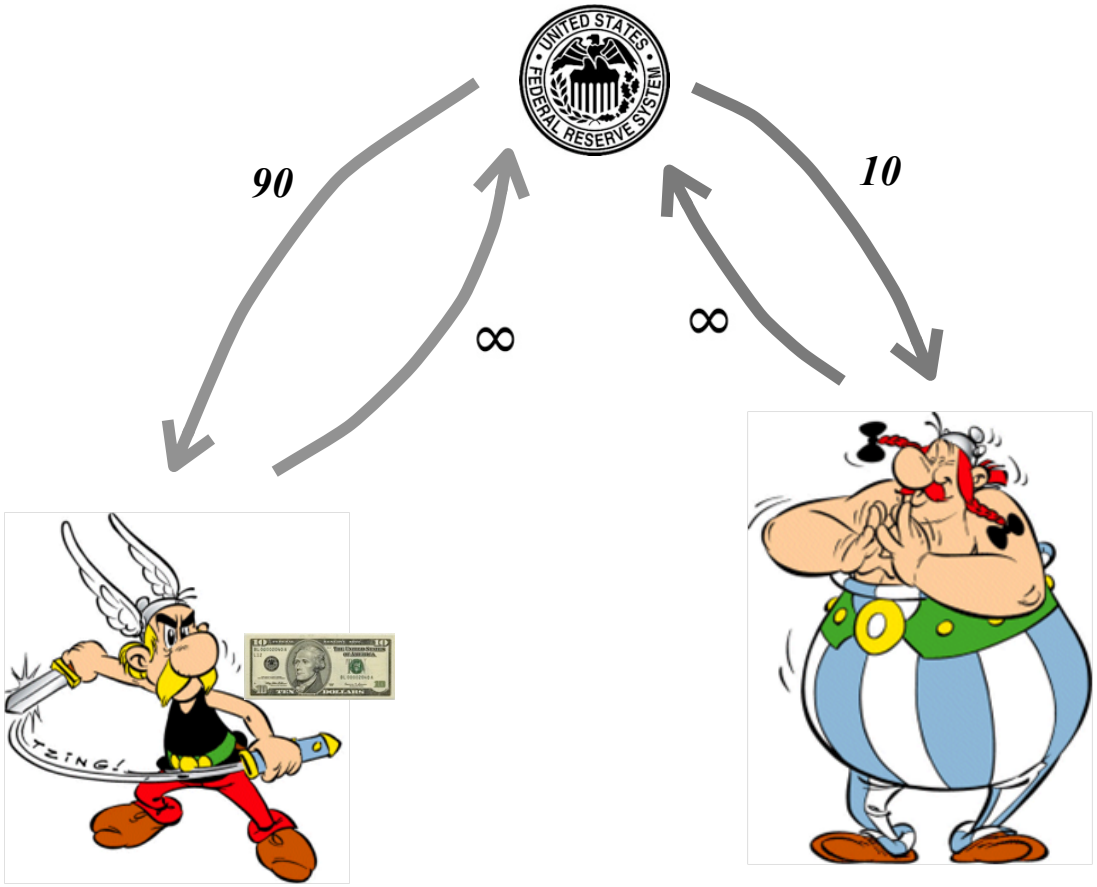


Illustration: Centralized Currency

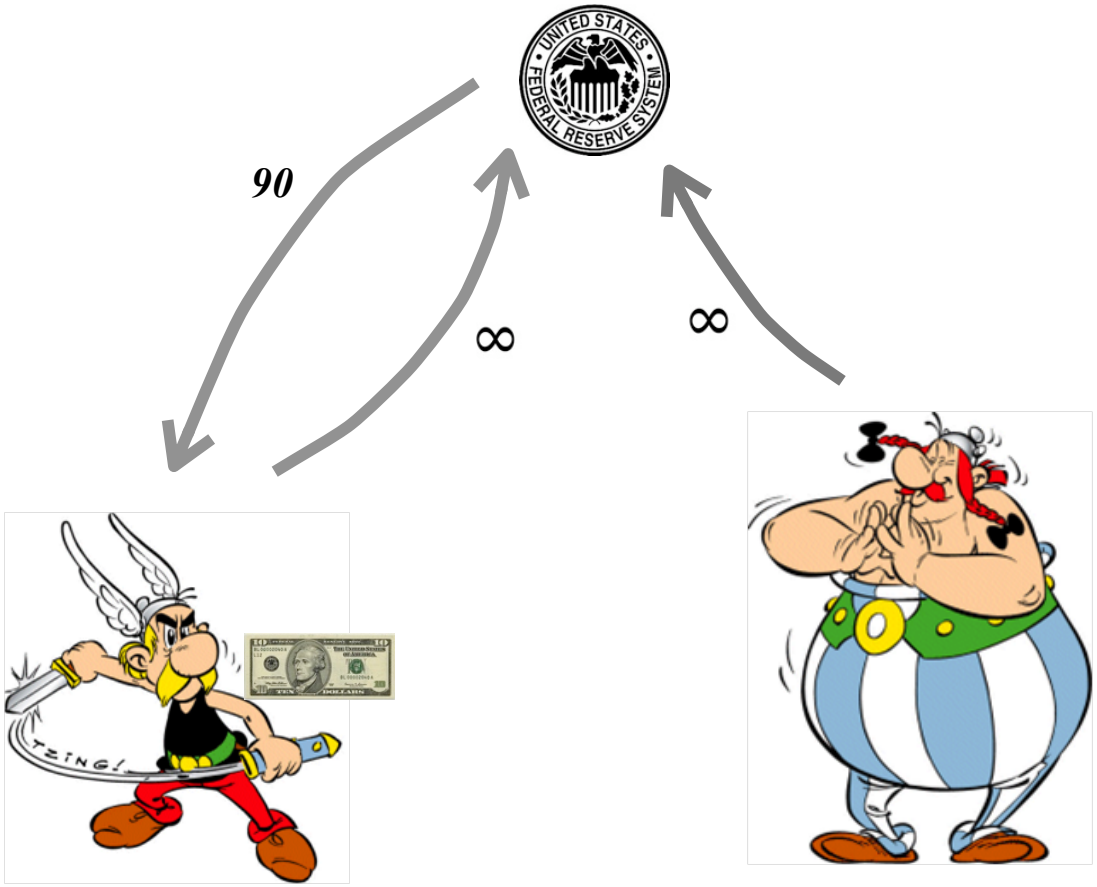


Illustration: Centralized Currency

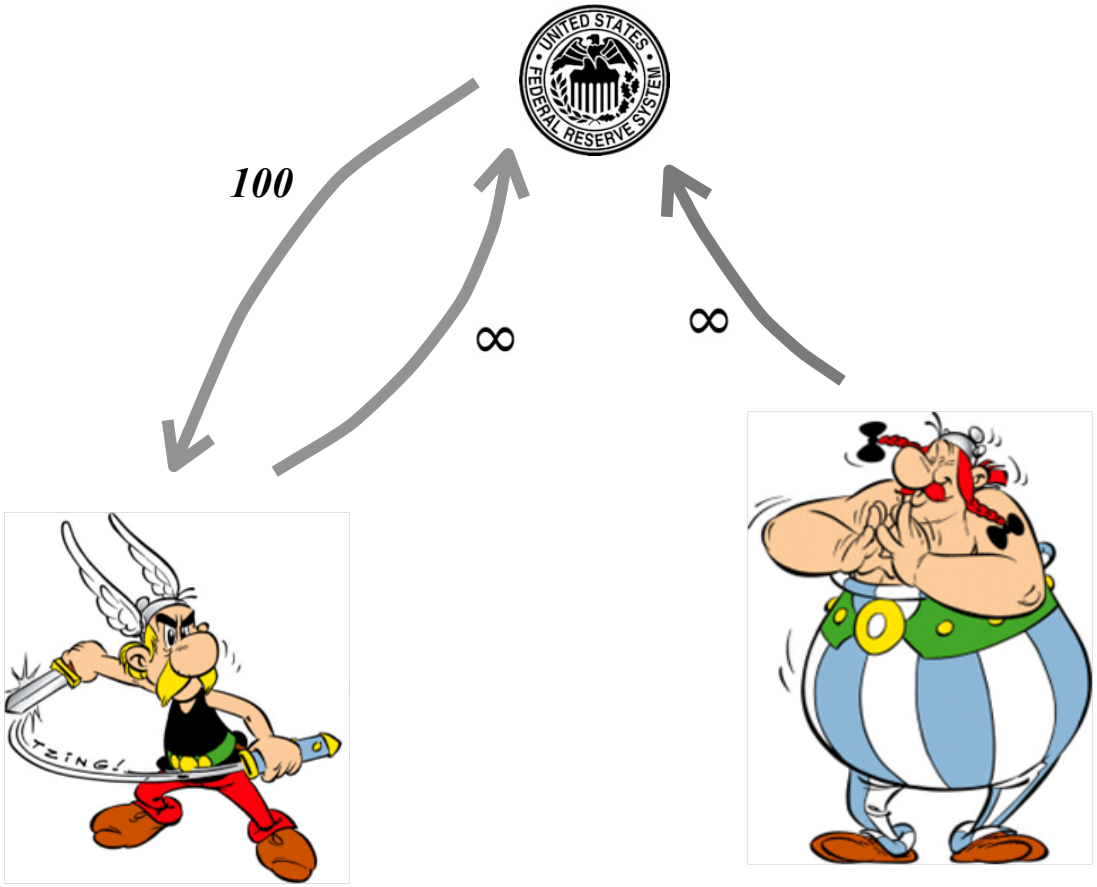


Illustration: Credit Networks

Illustration: Credit Networks

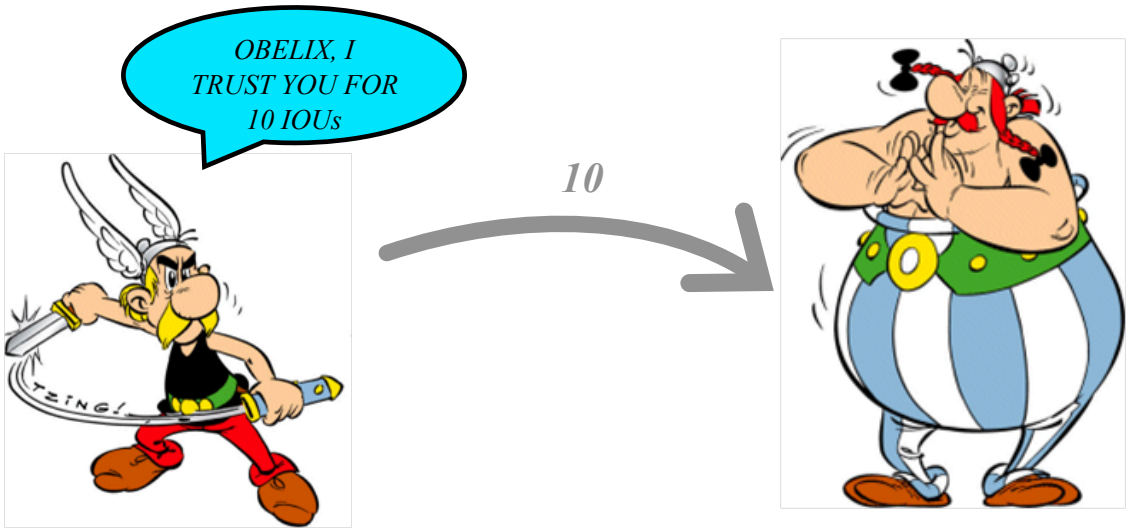


Illustration: Credit Networks

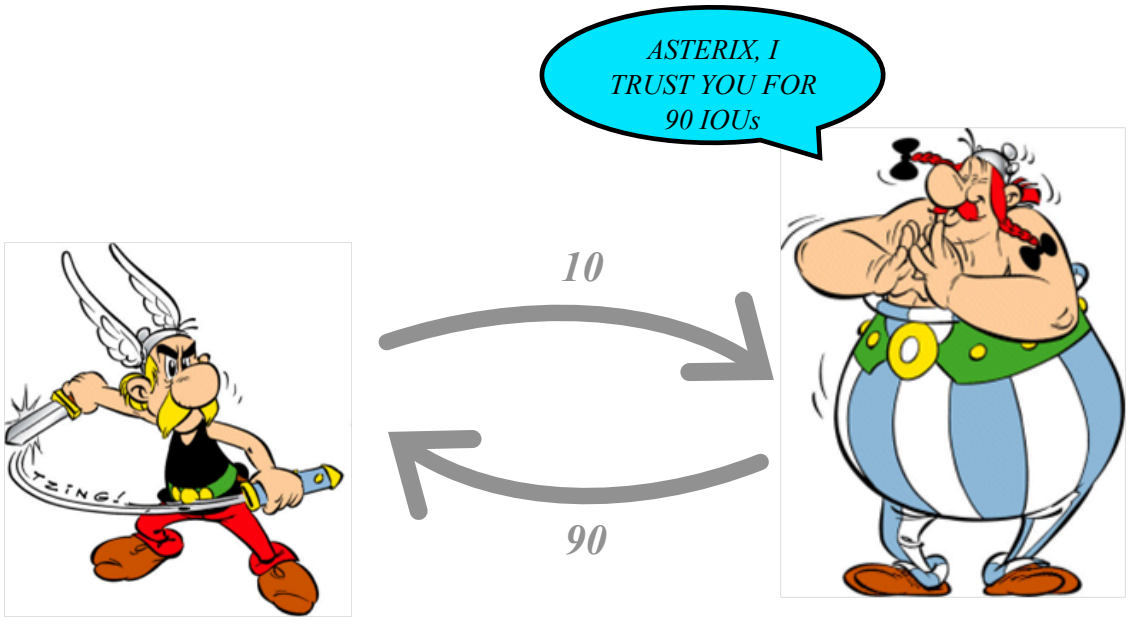


Illustration: Credit Networks

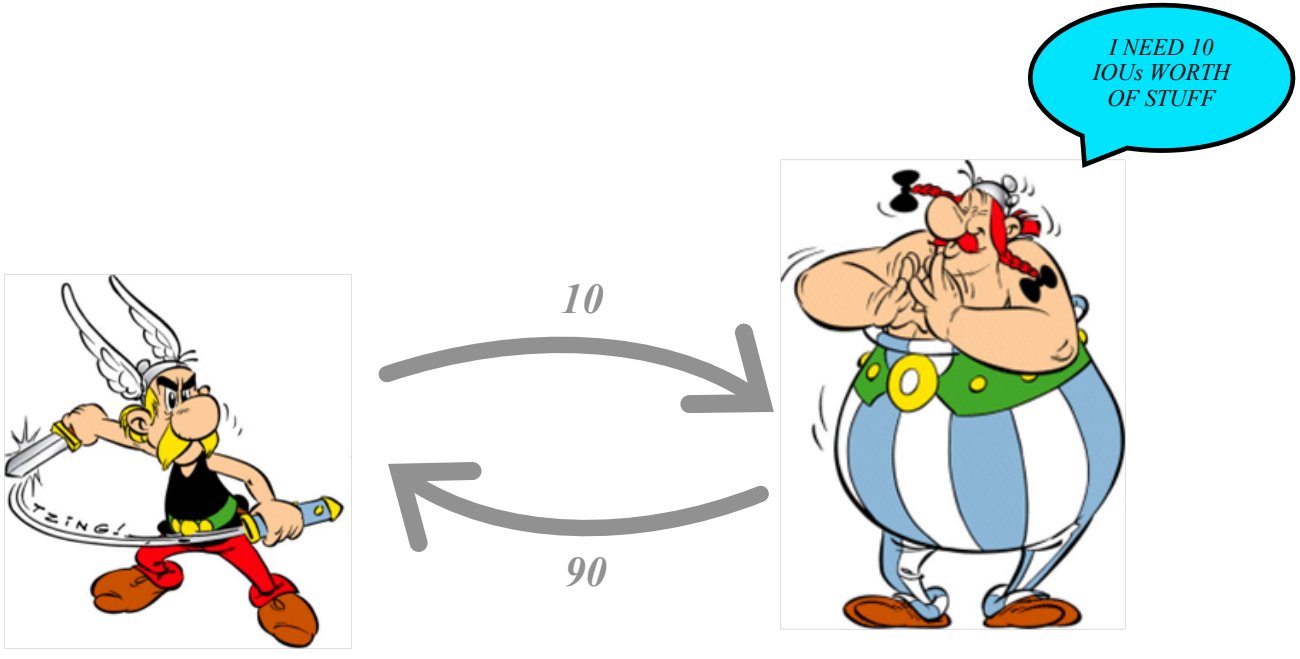


Illustration: Credit Networks

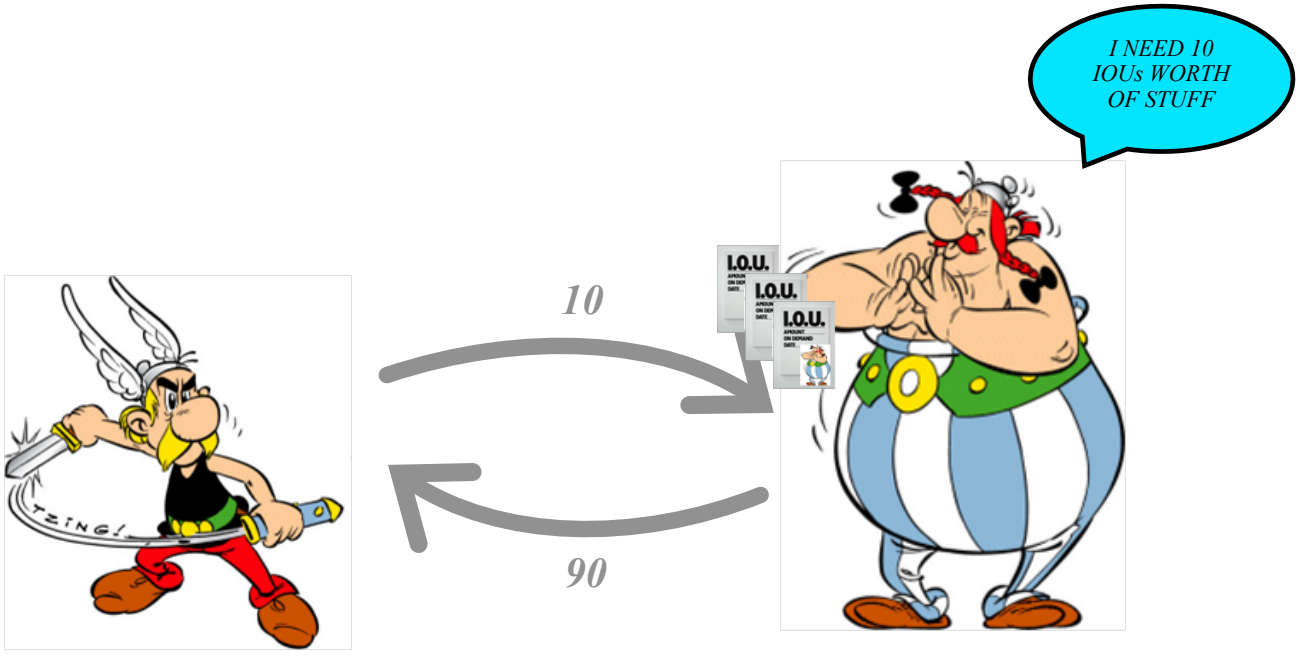


Illustration: Credit Networks

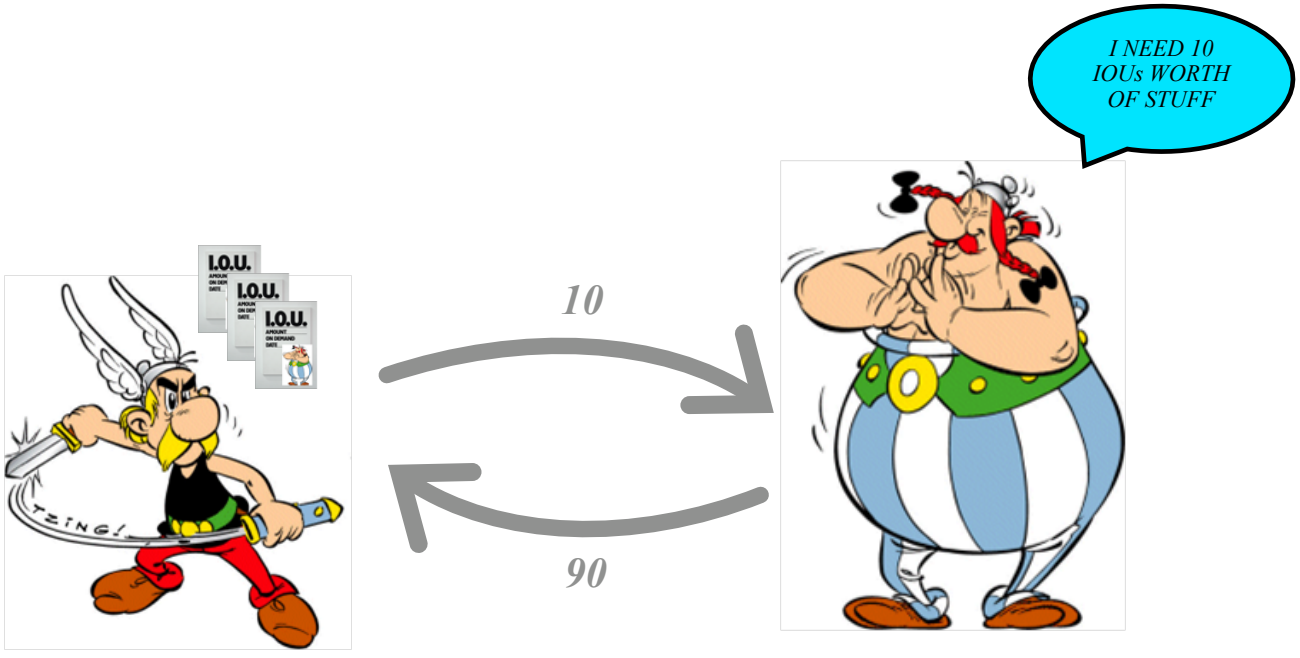
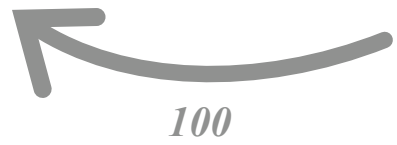


Illustration: Credit Networks



New Trust Values…

Illustration: Credit Networks

Interaction at a Distance

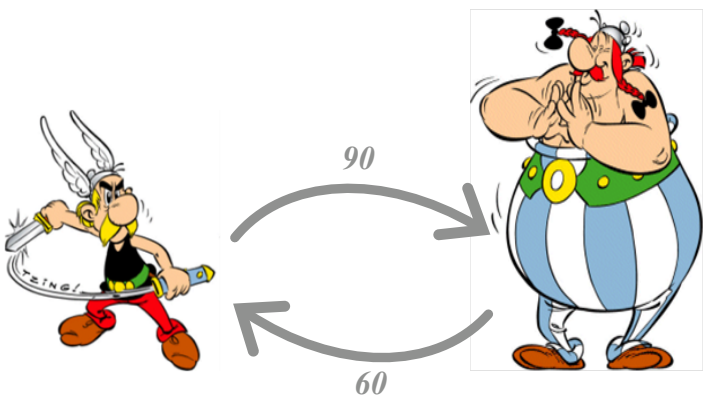


Illustration: Credit Networks

Interaction at a Distance

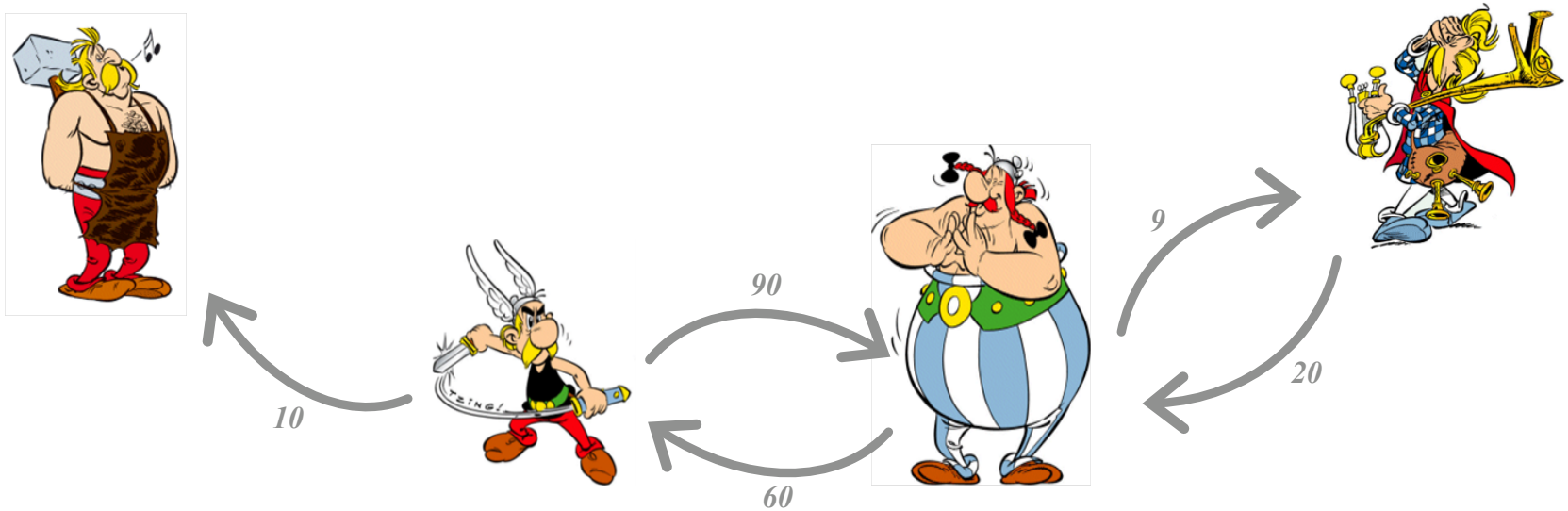


Illustration: Credit Networks

Interaction at a Distance

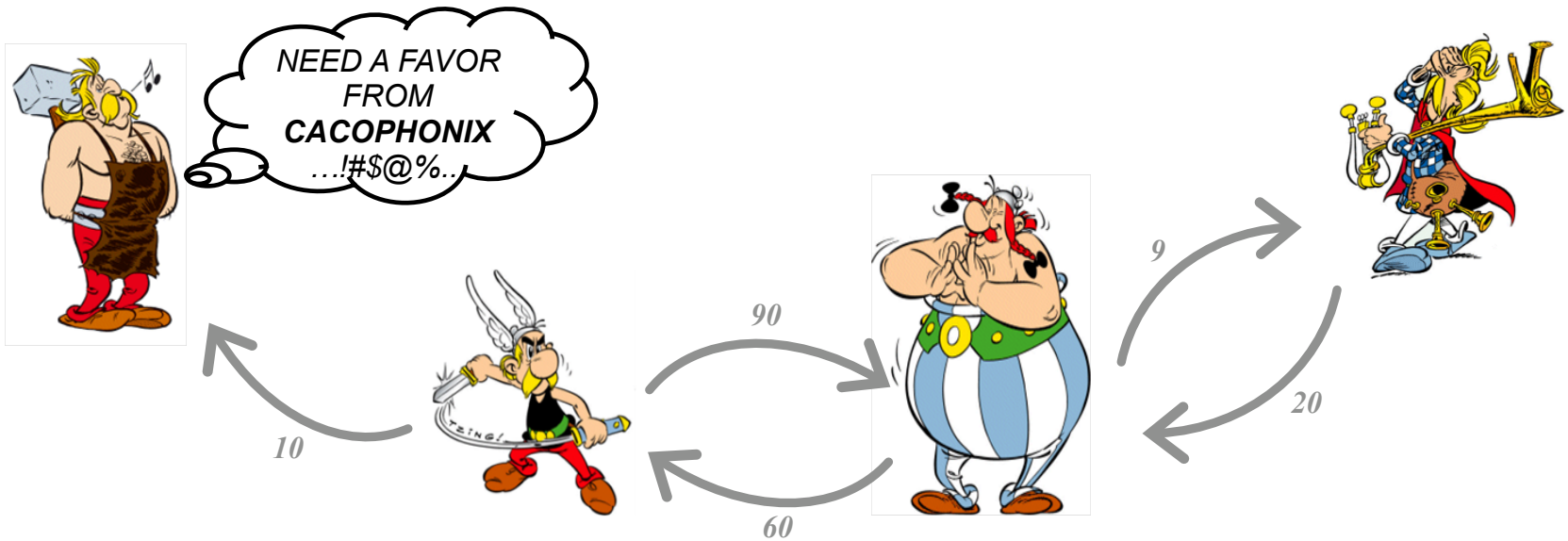


Illustration: Credit Networks

Interaction at a Distance

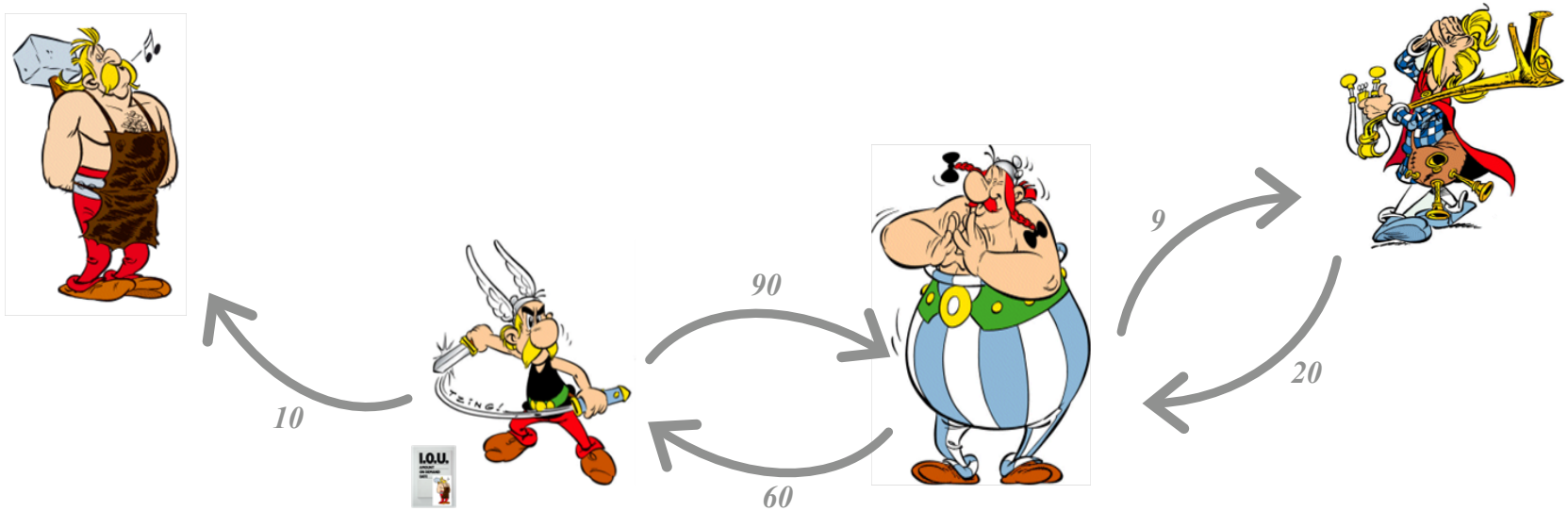


Illustration: Credit Networks

Interaction at a Distance

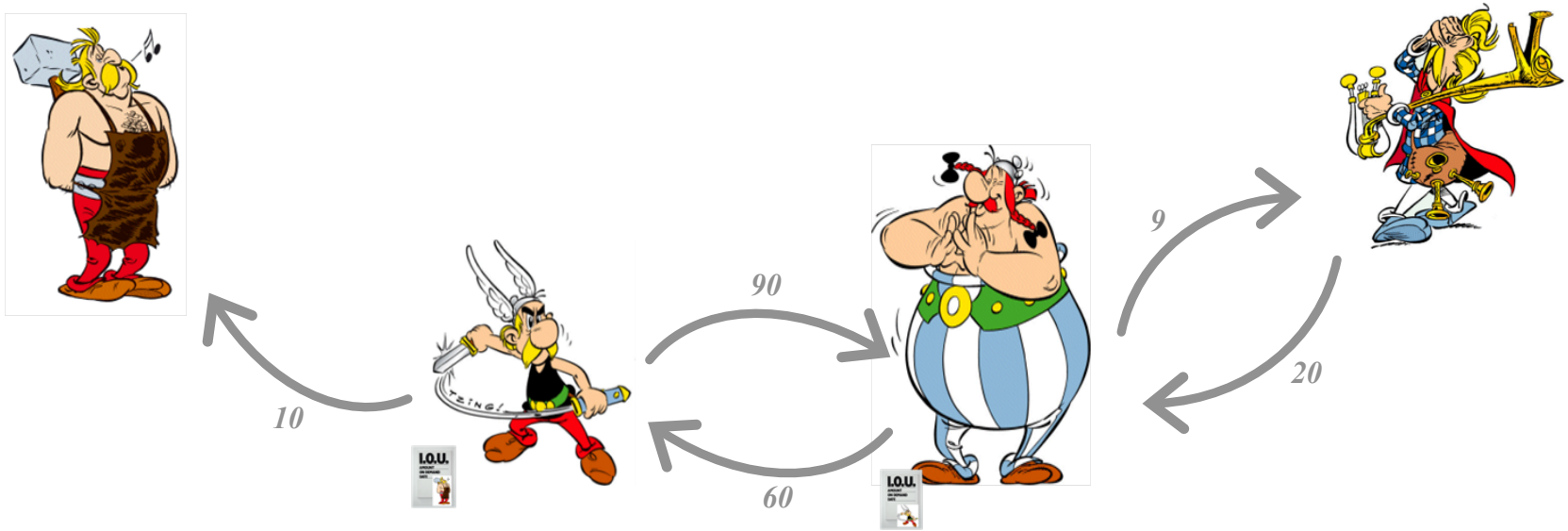


Illustration: Credit Networks

Interaction at a Distance

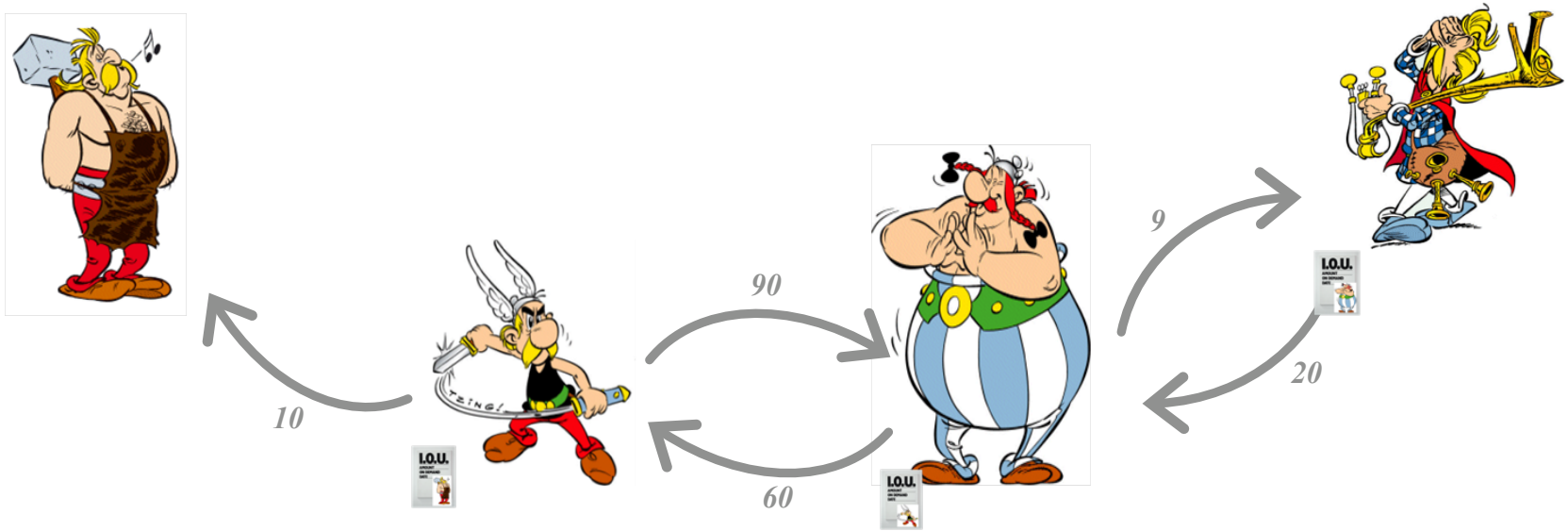


Illustration: Credit Networks

Interaction at a Distance

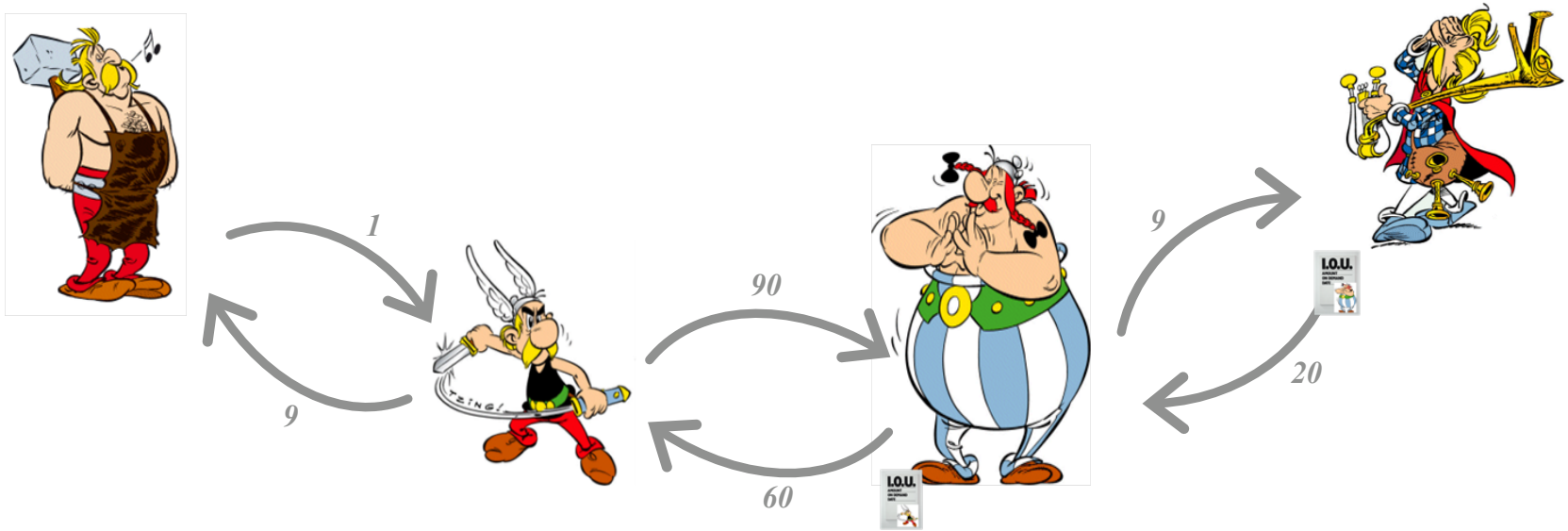


Illustration: Credit Networks

Interaction at a Distance

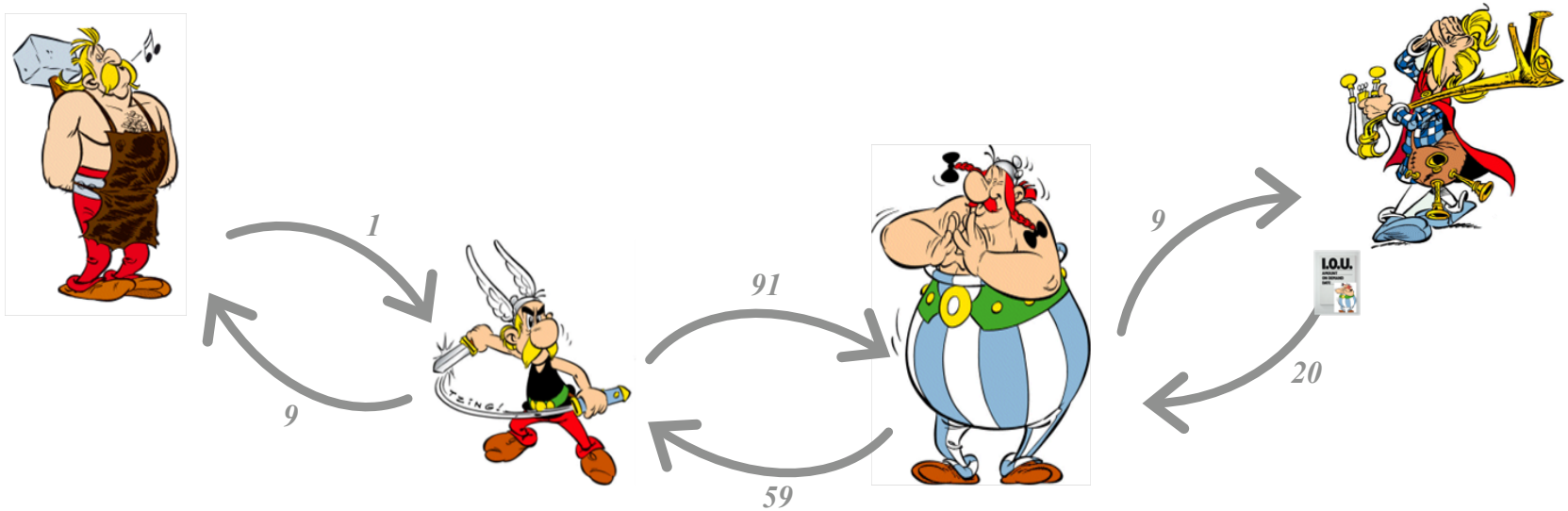
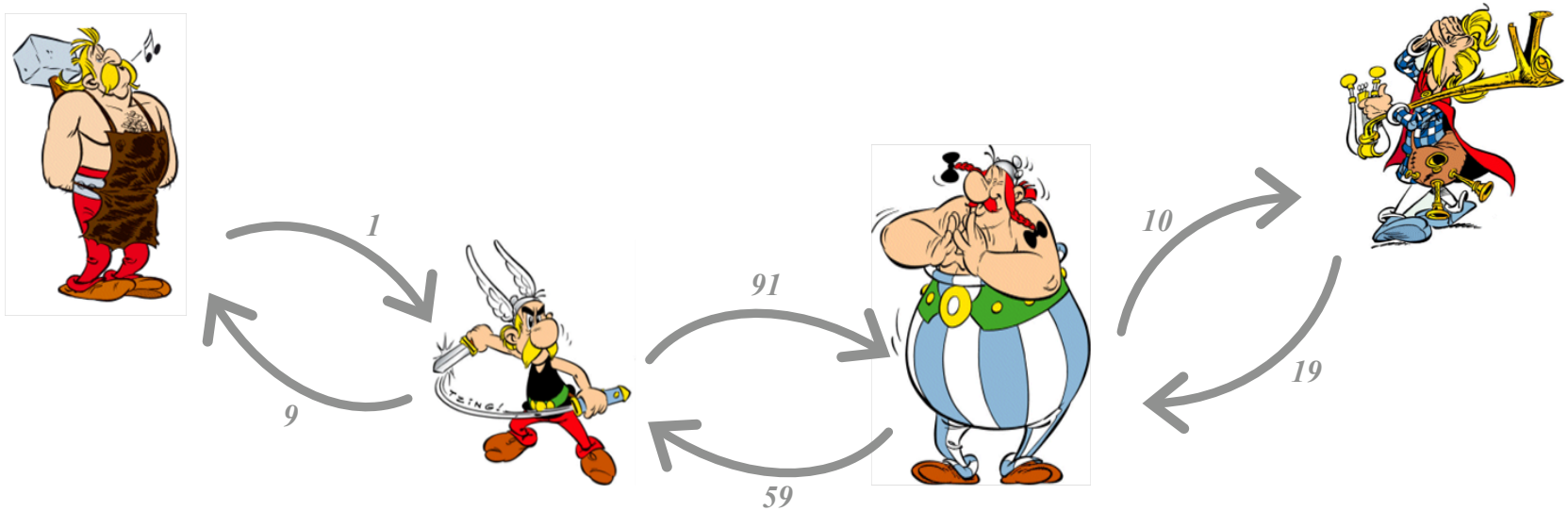


Illustration: Credit Networks

Interaction at a Distance



What is a Credit Network?

- Graph $G(V, E)$ represents a network (social network, p2p network, etc.)
- **Nodes:** (non-rational) agents/players; print their own currency
- **Edges:** credit limits $c_{uv} > 0$ extended by nodes to each other[1]
- Payments made by passing IOUs along a chain of trust. Same as augmentation of *single-commodity* flow along a path from payee to payer
- Credit gets replenished when payments are made in the other direction

Robustness: Every node is vulnerable to default only from its own neighbors, and only for the amount it directly trusts them for.

[1] assume all currency exchange ratios to be unity

What is a Credit Network?

- Graph $G(V, E)$ represents a network (social network, p2p network, etc.)
- **Nodes:** (non-rational) agents/players; print their own currency
- **Edges:** credit limits $c_{uv} > 0$ extended by nodes to each other[1]
- Payments made by passing IOUs along a chain of trust. Same as augmentation of *single-commodity* flow along a path from payee to payer
- Credit gets replenished when payments are made in the other direction

Robustness: Every node is vulnerable to default only from its own neighbors, and only for the amount it directly trusts them for.

[1] assume all currency exchange ratios to be unity

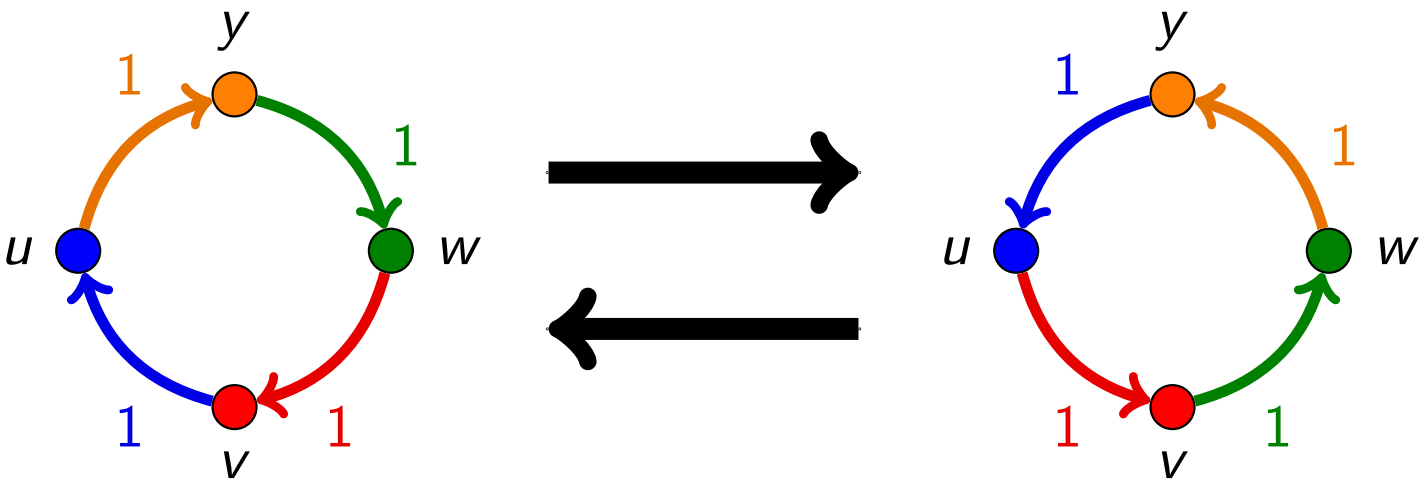
- Barter/Exchange economies like P2P networks.
- Insuring transactions in P2P commerce sites such as Craigs list
- Combating social spam (Facebook, LinkedIn)
- Email spam
- Question and Answer systems; Recommender systems

Research Questions

- Liquidity: Can credit networks sustain transactions for a long time, or does every node quickly get isolated?
- Network Formation: How do rational agents decide how much trust to assign to each other?

Liquidity Model

- Edges have integer capacity $c > 0$ (summing up both directions)
- Transaction rate matrix $\Lambda = \{\lambda_{uv} : u, v \in V, \lambda_{uu} = 0\}$
- Repeated transactions; at each time step choose (s, t) with prob. λ_{st}
- Try to route a unit payment from s to t via the shortest feasible path; **update edge capacities** along the path
- Transaction fails if no path exists



Definition

Let $\mathcal{S}$ and $\mathcal{S}'$ be two states of the network. We say that $\mathcal{S}'$ is **cycle-reachable** *from $\mathcal{S}$ if the network can be transformed from state $\mathcal{S}$ to state $\mathcal{S}'$ by routing a sequence of payments along feasible cycles (i.e. from a node to itself along a feasible path).*

Theorem

Let $(s_1, t_1), (s_2, t_2), \ldots, (s_T, t_T)$ be the set of transactions of value $v_1, v_2, \ldots, v_T$ respectively that succeed when the payment is routed along the shortest feasible path from s_i to t_i. Then the same set of transactions succeed when the payment is routed along any feasible path from s_i to t_i.

Proof Sketch.

Sending a unit of flow along two different paths from the same source to the same destination leads to two states that are cycle-reachable.

Cycle-reachability partitions all possible states of the credit network into equivalence classes.

Theorem

If the transaction rates are symmetric, then the network has a uniform steady-state distribution over all reachable equivalence classes.

Consequence: Yields a complete characterization of success probabilities in trees, cycles, or complete graphs; estimate for Erdös-Rényi graphs

Cycle-reachability partitions all possible states of the credit network into equivalence classes.

Theorem

If the transaction rates are symmetric, then the network has a uniform steady-state distribution over all reachable equivalence classes.

Consequence: Yields a complete characterization of success probabilities in trees, cycles, or complete graphs; estimate for Erdös-Rényi graphs

Cycle-reachability partitions all possible states of the credit network into equivalence classes.

Theorem

If the transaction rates are symmetric, then the network has a uniform steady-state distribution over all reachable equivalence classes.

Consequence: Yields a complete characterization of success probabilities in trees, cycles, or complete graphs; estimate for Erdös-Rényi graphs

Assume capacity c. Then we have $c + 1$ states; each in a different equivalence class.

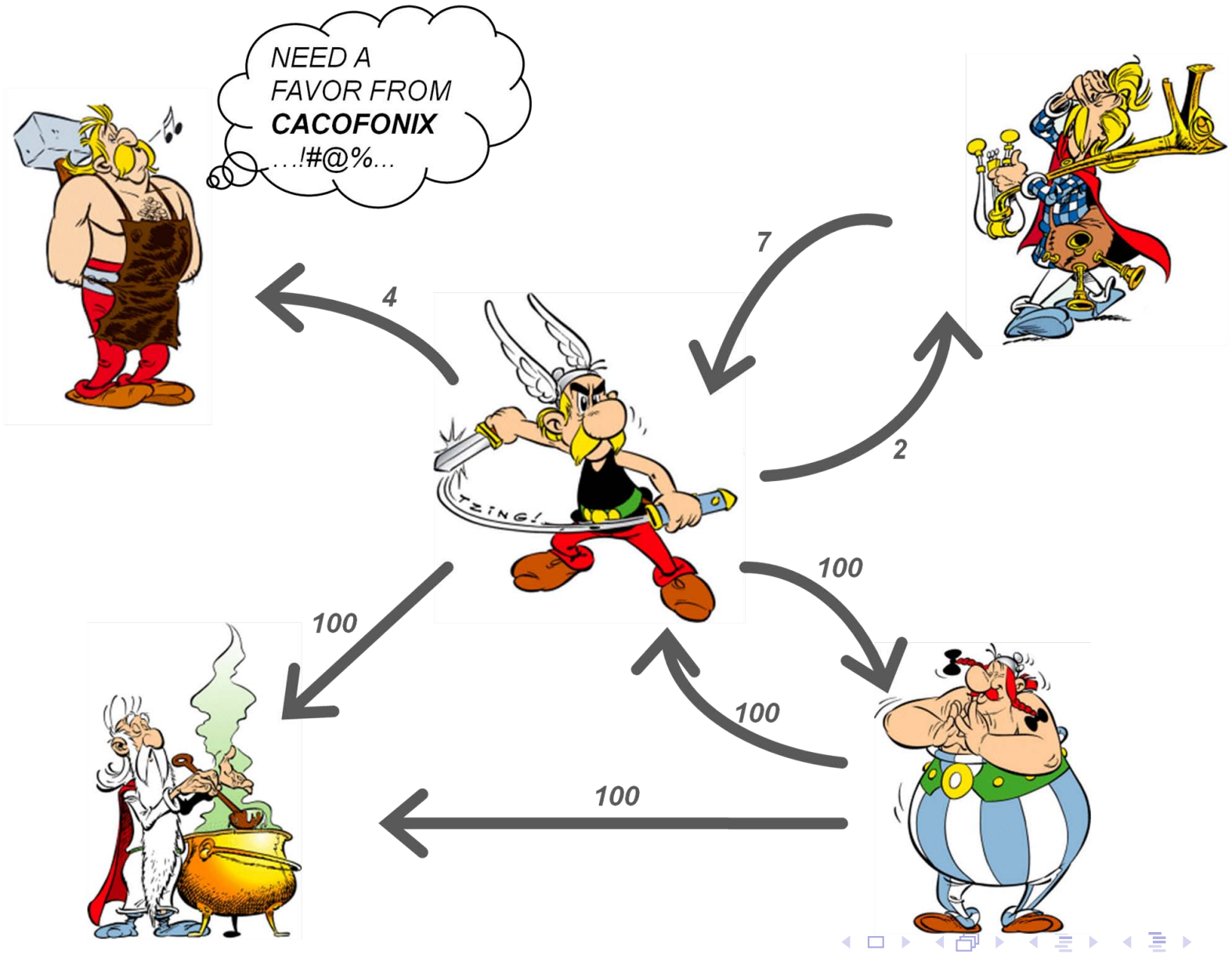
Success probability for a transaction is $c/(c + 1)$.

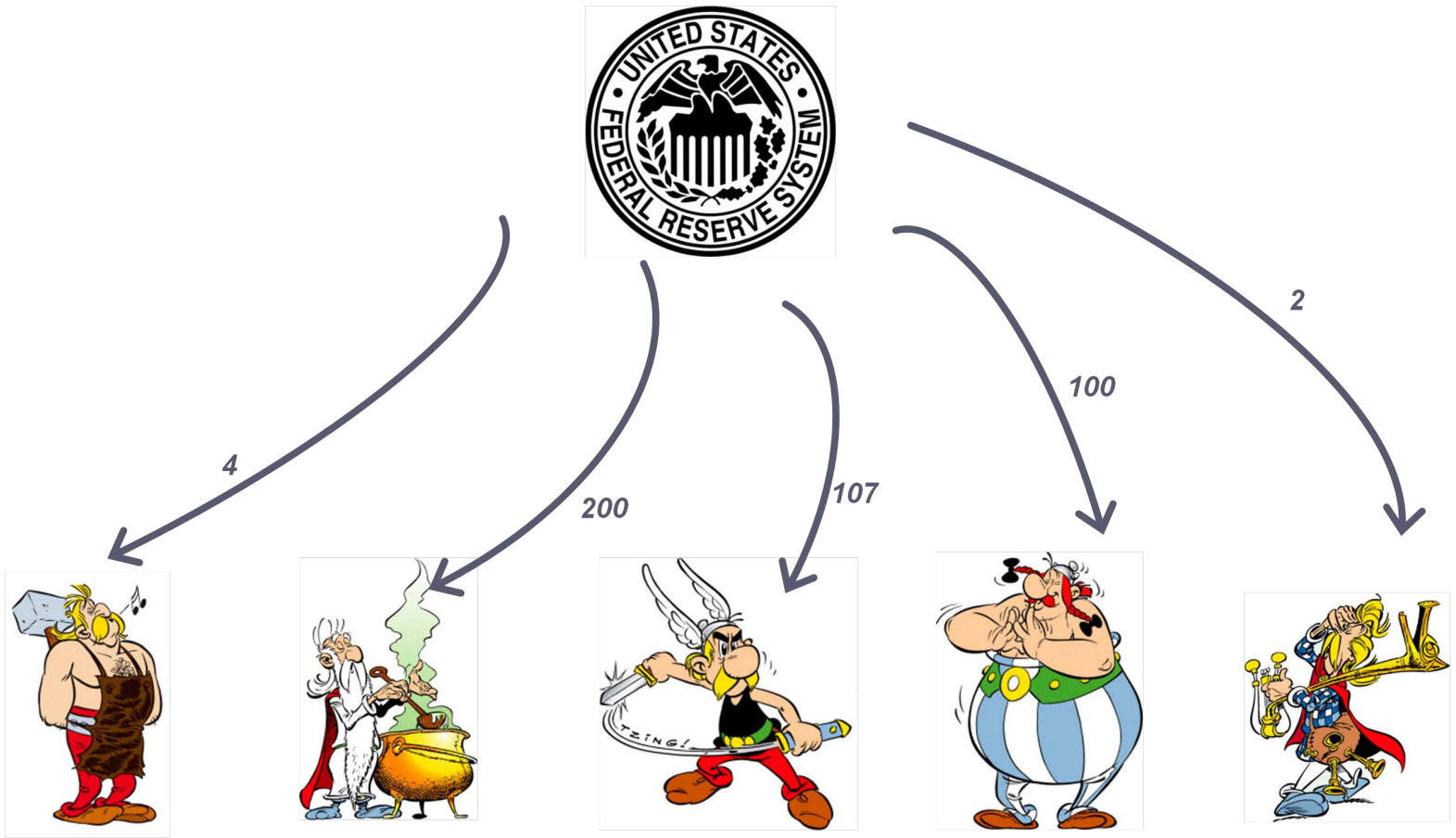
No cycles. Hence, all states are equally likely.

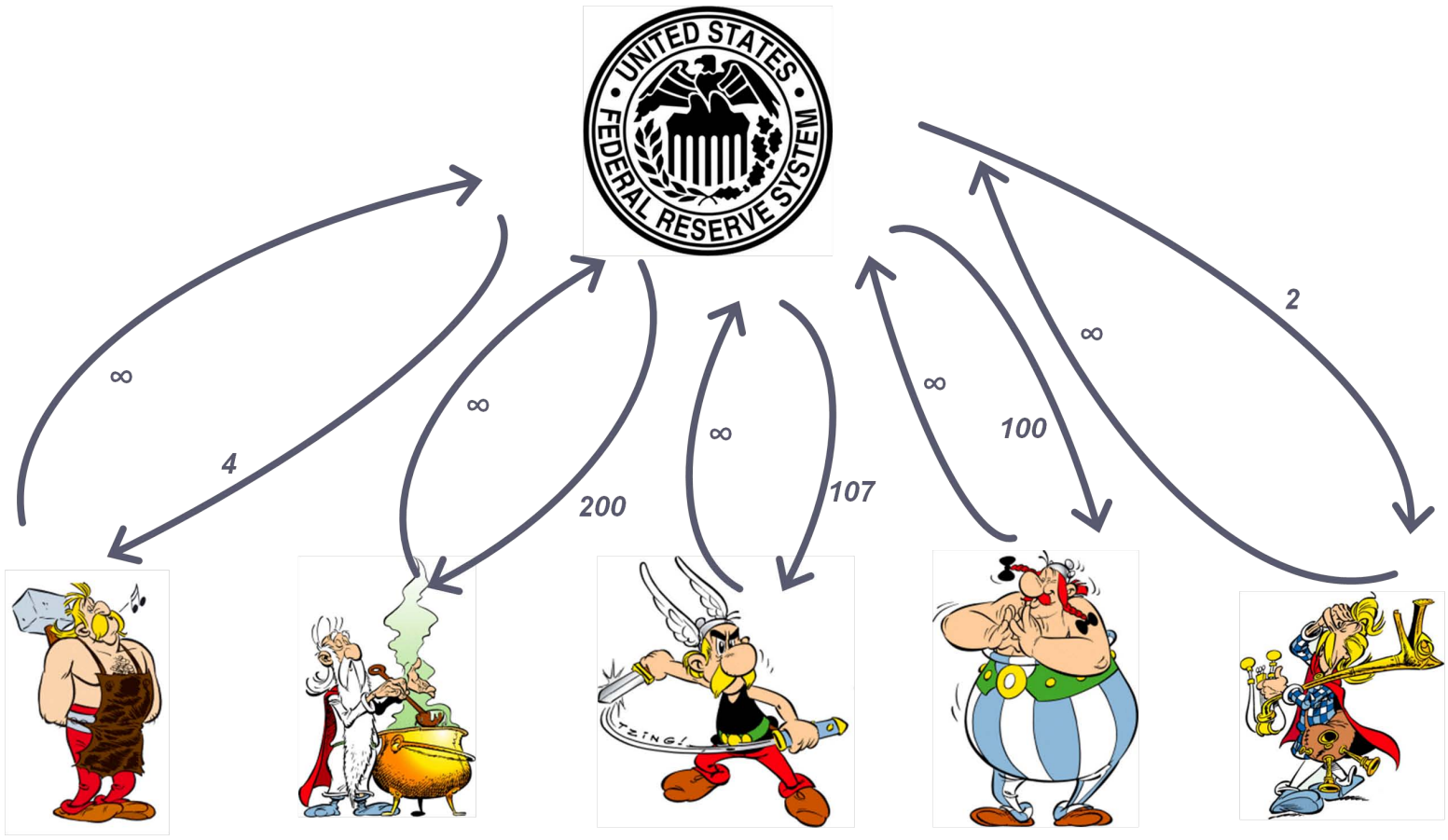
Let $c_1, c_2, \ldots, c_L$ be the capacities along the path from s to t in the tree. Then, success probability is

$$\prod_{i=1}^{L} c_i/(c_i + 1).$$

Assume capacity $c = 1$ on each edge, and the Markov chain is ergodic. Let d_v denote the degree of node v. Then the stationary probability that v is bankrupt is at most $1/(1 + d_v)$.


NEED A
FAVOR FROM
CACOFONIX
...!#@%...
4
7
2
100
100
100
100
TZING!


UNITED STATES
FEDERAL RESERVE SYSTEM
4
200
107
100
2
TZING!


UNITED STATES
FEDERAL RESERVE SYSTEM
∞
4
∞
200
∞
107
∞
100
∞
2

Convert Credit Network $\rightarrow$ Centralized Model

$$\forall u, c_{ru} = \sum_{v} c_{vu}$$

$\Longrightarrow$ Total credit in the system is conserved during conversion

Slight variant of the liquidity analysis gives steady state distribution and success probabilities.

Convert Credit Network → Centralized Model

$$\forall u, c_{ru} = \sum_{v} c_{vu}$$

$\Longrightarrow$ Total credit in the system is conserved during conversion

Slight variant of the liquidity analysis gives steady state distribution and success probabilities.

Convert Credit Network $\rightarrow$ Centralized Model

$$\forall u, c_{ru} = \sum_{v} c_{vu}$$

$\Longrightarrow$ Total credit in the system is conserved during conversion

Slight variant of the liquidity analysis gives steady state distribution and success probabilities.

Bankruptcy probability

Graph class	Credit Network	Centralized System
General graphs	$\leq 1/(d_v + 1)$	$\approx 1/d_{AVG}$

Transaction failure probability

Graph class	Credit Network	Centralized System
Star-network	$\Theta(1/c)$	$\Theta(1/c)$
Complete Graph	$\Theta(1/nc)$	$\Theta(1/nc)$
$G_c(n, p)$	$\Theta(1/npc)$	$\Theta(1/npc)$

Table: Steady-state Failure Probability in Credit Network v/s Centralized System

Summary: Credit networks have liquidity which is almost the same as that in centralized currency systems.


Dimitri B. DeFigueiredo and Earl T. Barr
Trustdavis: A non-exploitable online reputation system, CEC 2005


Arpita Ghosh, Mohammad Mahdian, Daniel M. Reeves, David M. Pennock, and Ryan Fugger
Mechanism design on trust networks, WINE 2007.