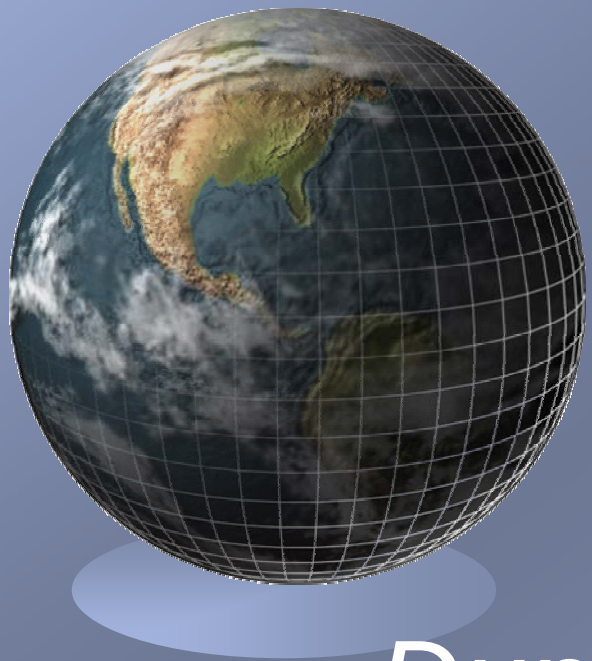
Six Degrees:
The Science of a Connected Age

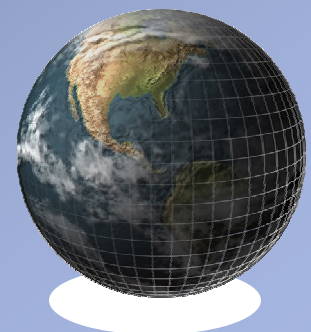


Duncan Watts

Columbia University

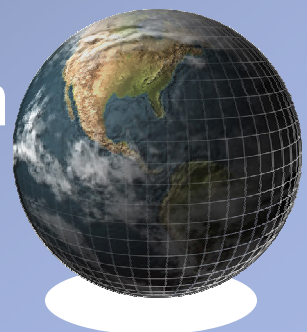
Outline

- The Small-World Problem
- What is a “Science of Networks”?
- Why does it matter?



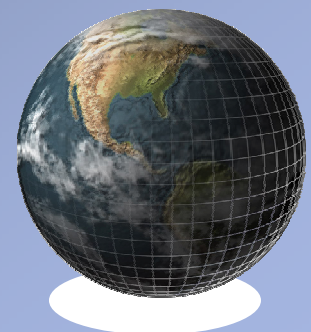
Six Degrees

- “Six degrees of separation between us and everyone else on this planet”
  - John Guare, 1990
- An urban myth? (“Six handshakes to the President”)
- First mentioned in 1920’s by Karinthy
- 30 years later, became a research problem



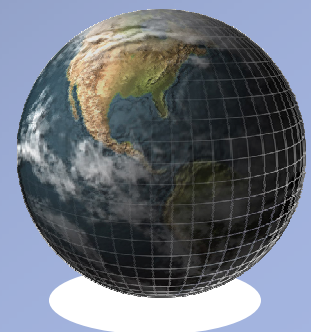
The Small World Problem

- In the 1950's, Pool and Kochen asked "what is the probability that two strangers will have a mutual friend?"
  - i.e. the "small world" of cocktail parties
- Then asked a harder question: "What about when there is no mutual friend--how long would the chain of intermediaries be?"
- How can one account for "clustering" bias of social networks
  - Homophily (Lazarsfeld and Merton)
  - Triadic Closure (Rapoport)
- Too hard…



The Small World Experiment

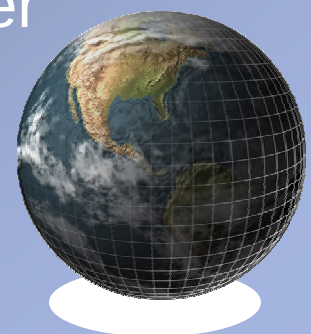
- Stanley Milgram (and student Jeffrey Travers) designed an experiment based on Pool and Kochen's work
  - A single "target" in Boston
  - 300 initial "senders" in Boston and Omaha
  - Each sender asked to forward a packet to a friend who was "closer" to the target
  - The friends got the same instructions



“Six Degrees of Separation”

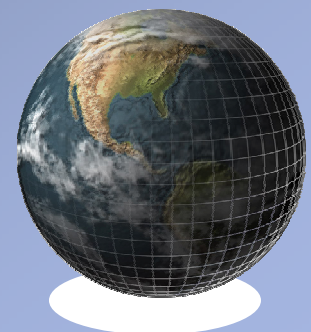
- Travers and Milgram’s protocol generated 300 “letter chains” of which 64 reached the target.
- Found that typical chain length was 6
- Led to the famous phrase (Guare)

- Then not much happened for another 30 years.
  - Theory was too hard to do with pencil and paper
  - Data was too hard to collect manually



A New Approach

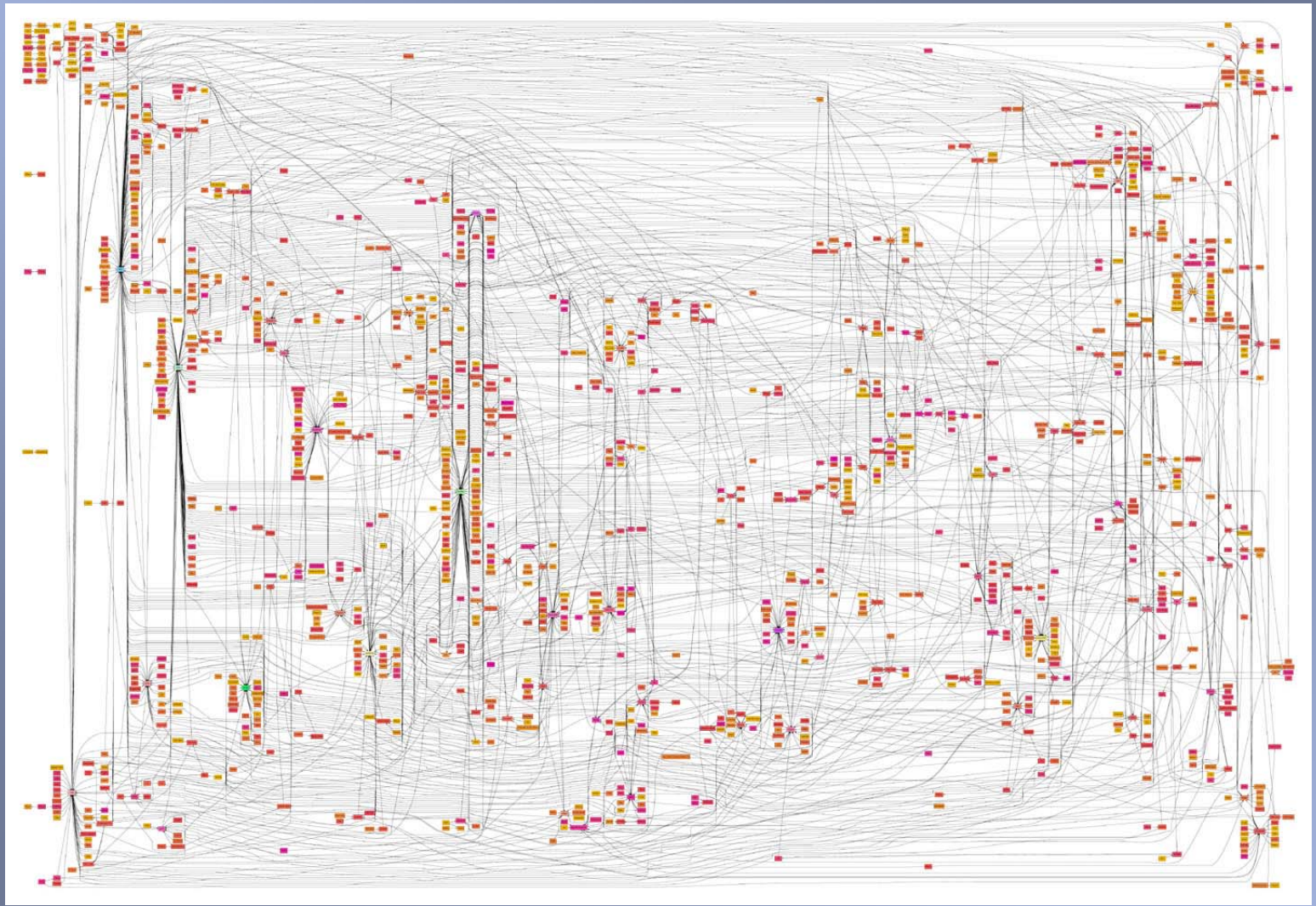
- Mid 90's, Steve Strogatz and I working on another problem altogether
- Decided to think about this urban myth
- We had three advantages
  - We didn't know about previous work
  - We had MUCH faster computers
  - Our background was in physics and mathematics
- Result was that we approached the problem quite differently



Small World Networks

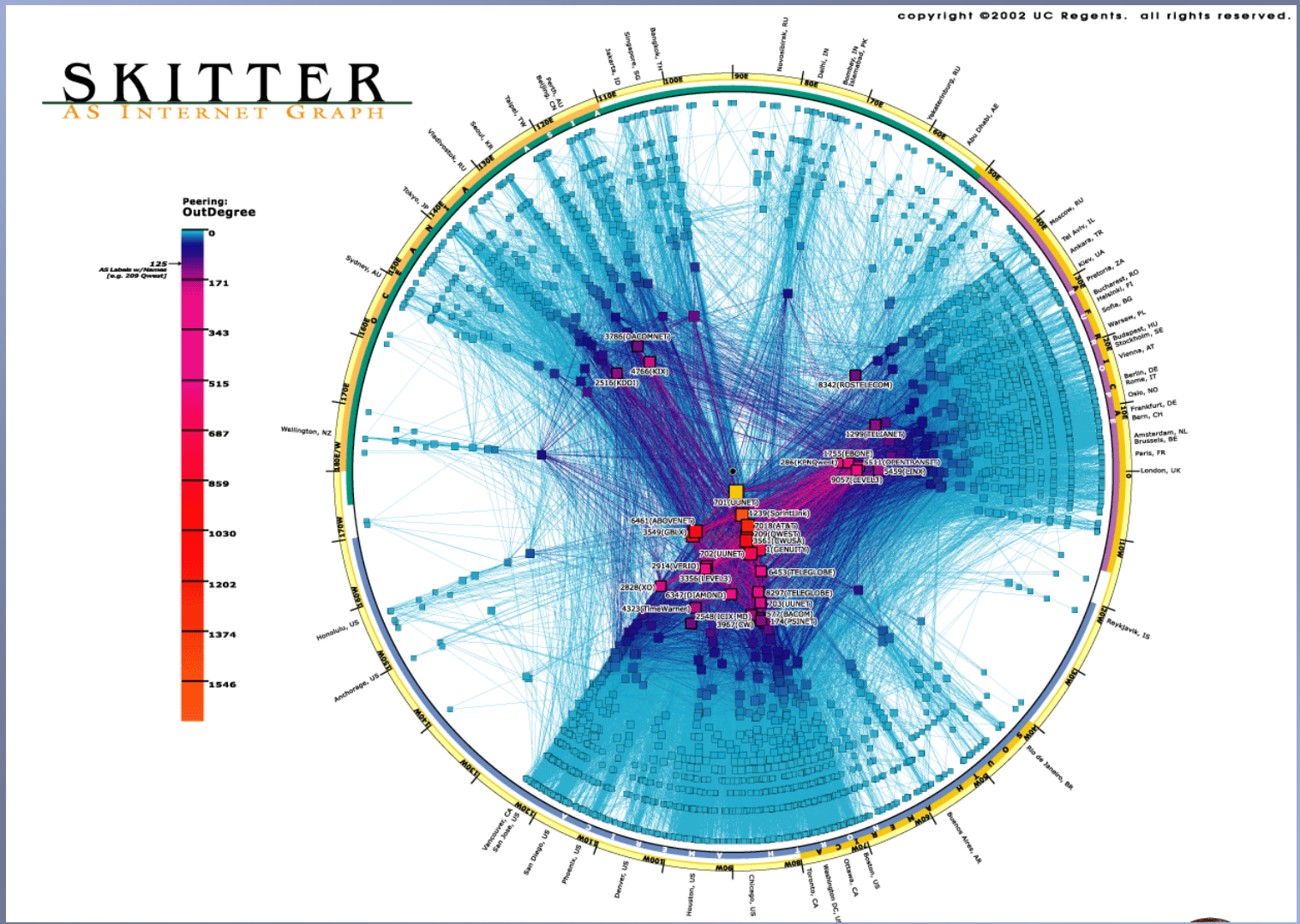
- Instead of asking “How small is the actual world?”, we asked “What would it take for any world at all to be small?
- Question has three *kinds* of answers:
  - “small-world” networks are impossible
    - Either short paths or high clustering,but not both
  - Possible, but conditions are stringent
  - Conditions are easy to satisfy
- As it turned out, required conditions are trivial
  - Some source of “order”
  - The tiniest amount of randomness
- Small World Networks should be *everywhere*

Online Social Relationships

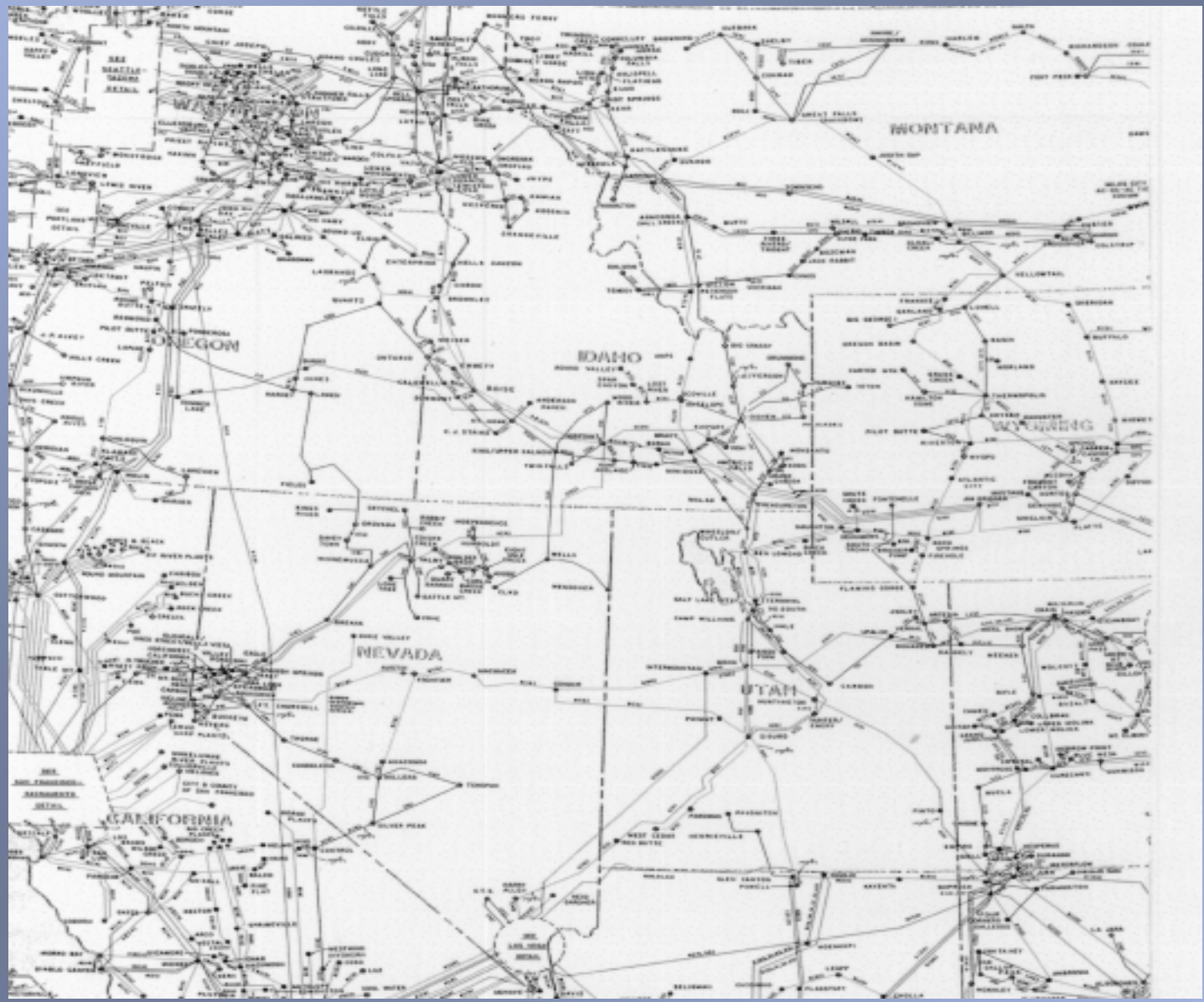


[Isbell et al.]

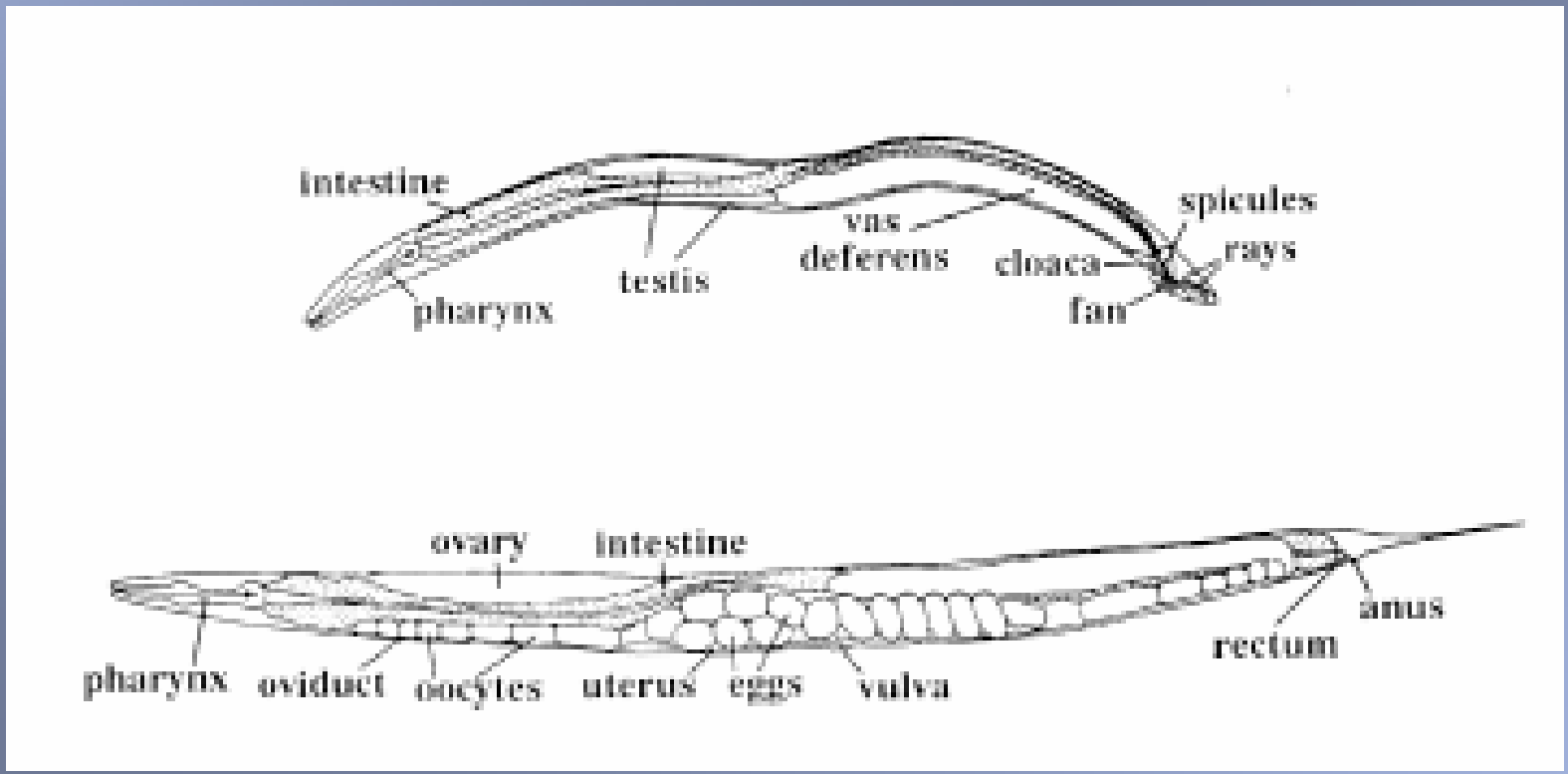
Internet Connections (CAIDA)



Power Transmission Grid of Western US



C. Elegans


intestine
pharynx
testis
vas
deferens
cloaca
spicules
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intestine
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oocytes
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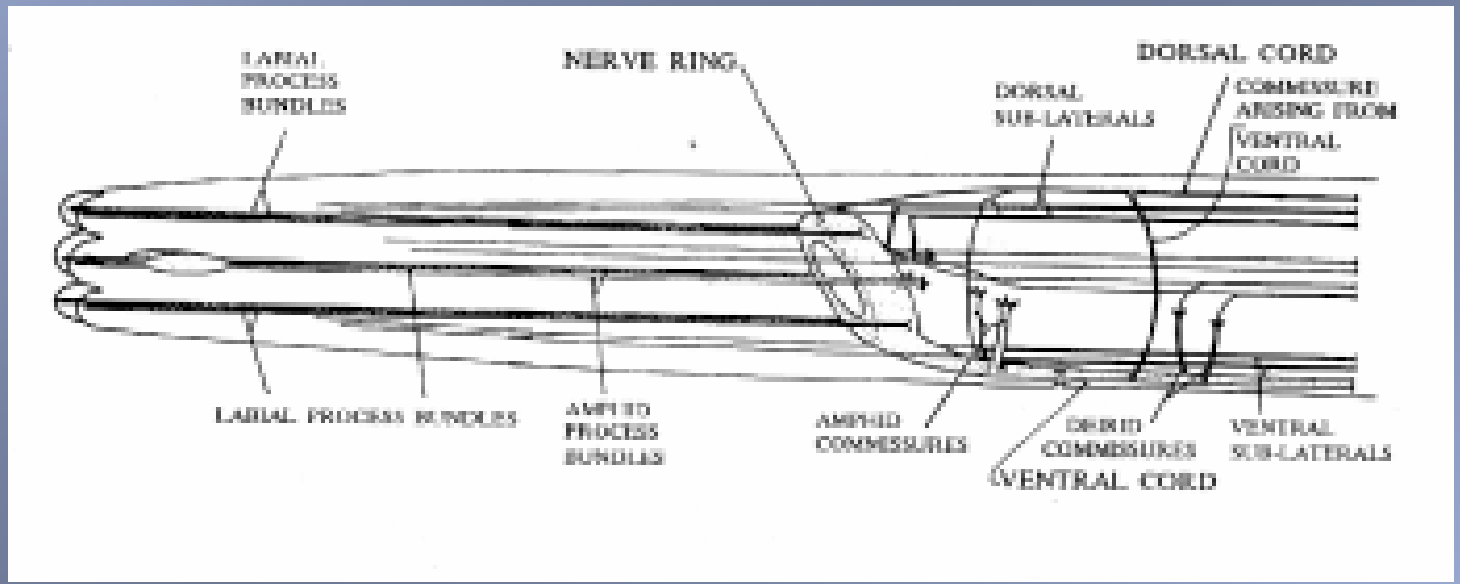
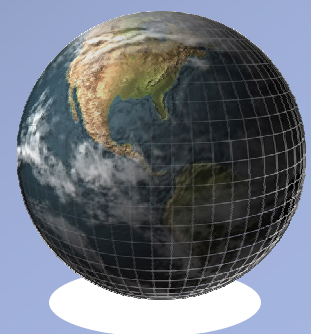
eggs
vulva
rectum
anus

Neural network of *C. elegans*



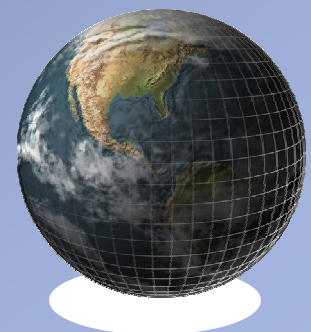
Six years later…

- We (collectively) have a good understanding of how the small world phenomenon works
- Also starting to understand other characteristics of large-scale networks
- New theories, better methods, faster computers, and electronic recording all contributing to rapid scientific advance



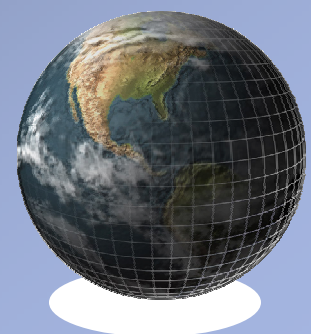
A “New” Science of Networks?

- Where do networks arise?
- Why do they matter?

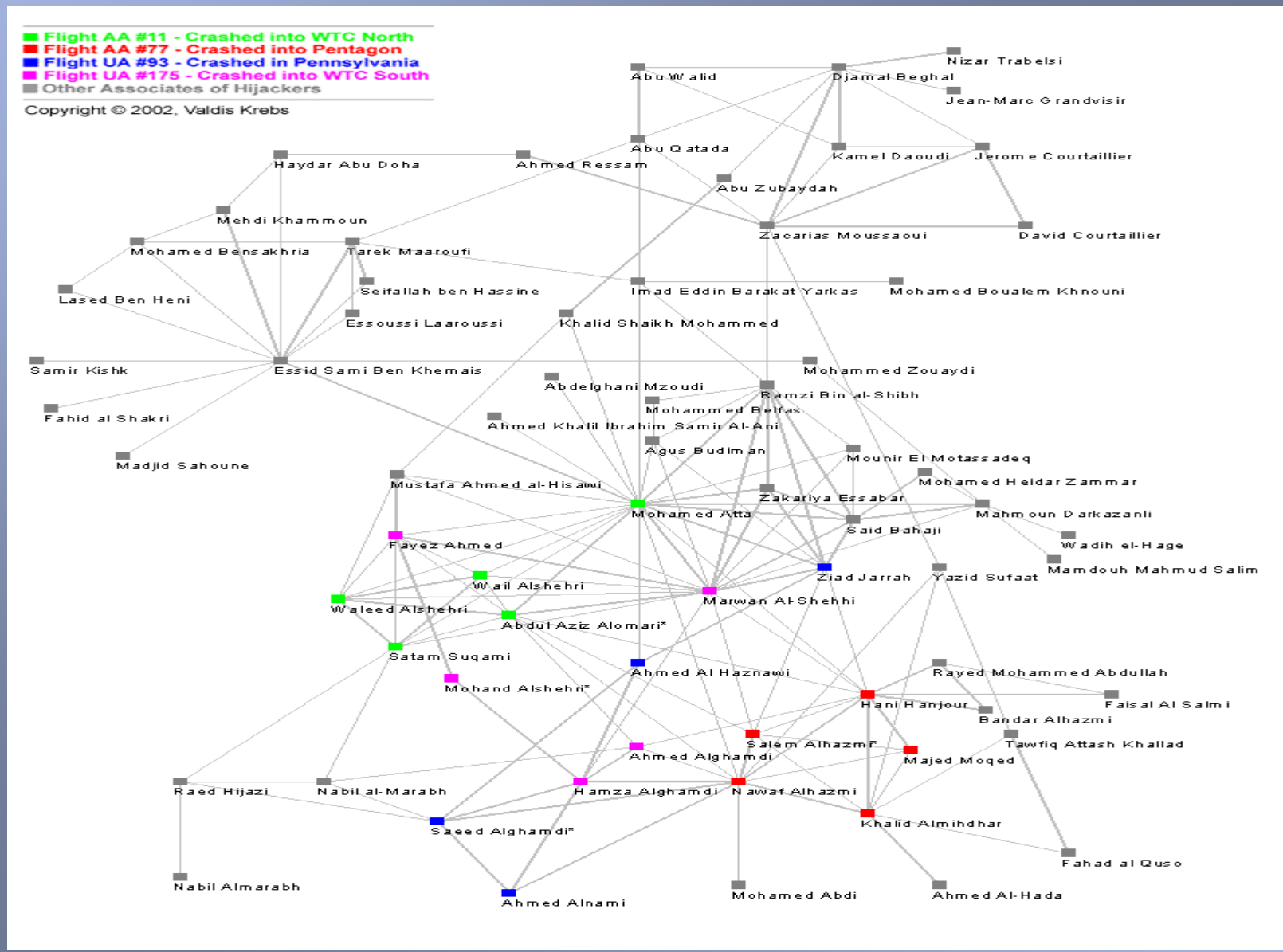


Where do networks Arise?

- Lots of important problems can be represented as networks
  - Firms, Markets, Economies
  - Friendships, Families, Affiliations
  - Disease transmission, Food webs, Ecosystems
  - Neural, metabolic, genetic regulatory networks
  - Citations, words, characters, historical events
- In fact, any system comprising many individuals between which some relation can be defined can be mapped as a network
- Networks are ubiquitous!



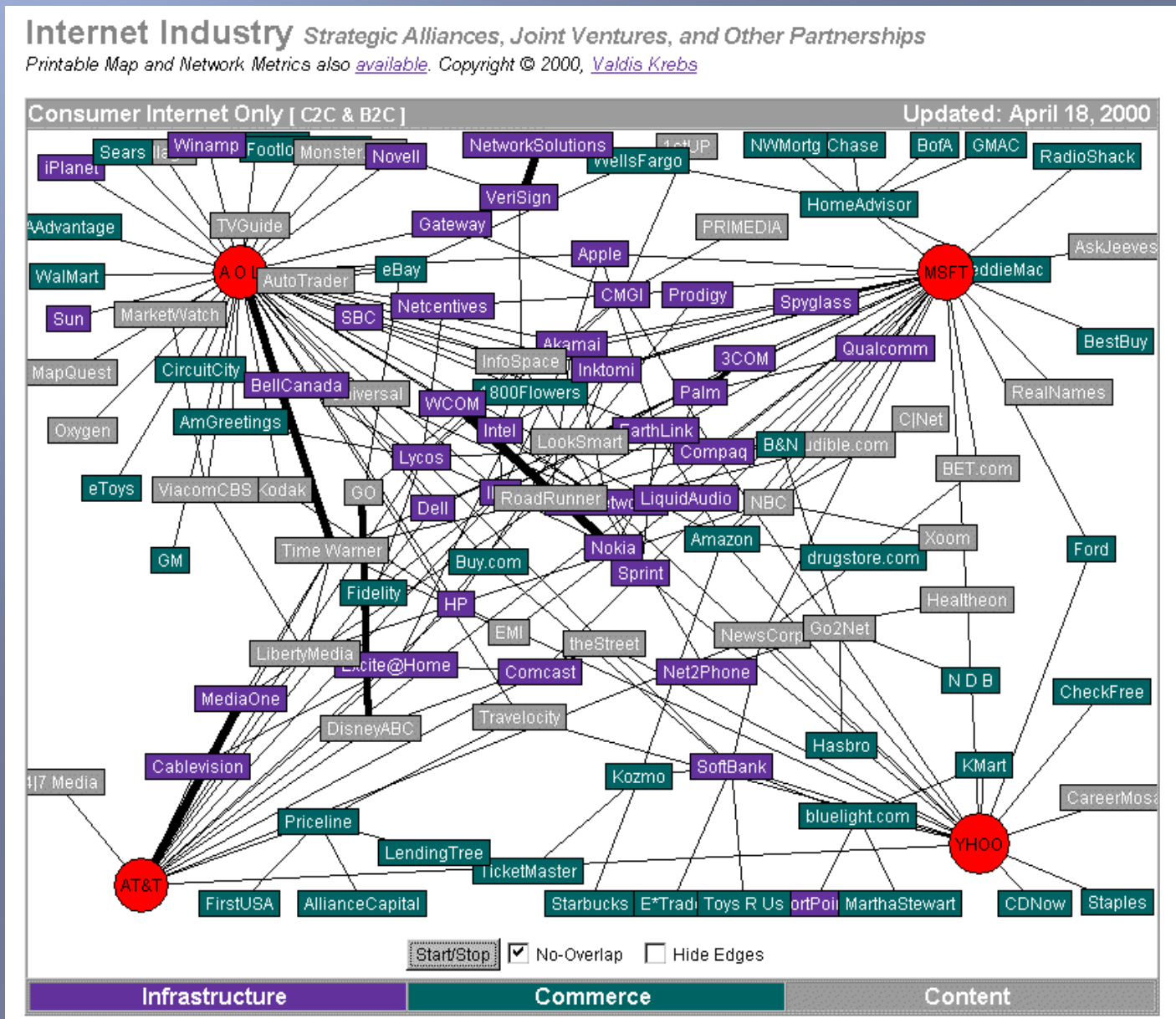
The Sept 11 Hijackers and their Associates



Syphilis transmission in Georgia

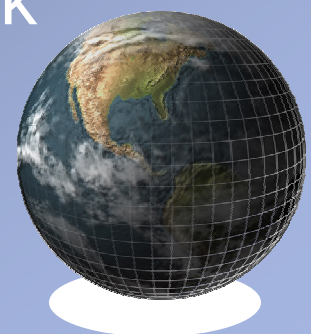
Network Visualization of the Outbreak

Corporate Partnerships



Why do networks matter?

- It may be so that lots of problems can be represented as networks
- But so what? What we really want to know is: How does the network affect *behavior*?
- Specially interested in collective behavior: what happens when lots of people, each following their own rules, interact?
- Interactions are described by the network
- Hard problem, because normally we think about individual behavior

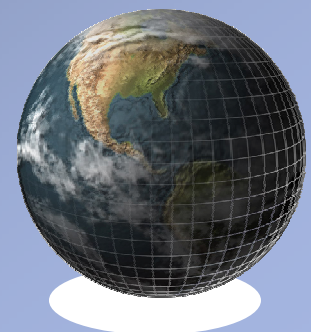


An Example: Making Decisions

- According to Micro-economics, people are supposed to know what they want and make “rational” decisions
- But in many scenarios, either
  - We don’t have enough information; or
  - We can’t process the information we do have
  - Often there is a premium on *coordinated* response (culture, conventions, coalitions, coups)
- Sometimes we don’t even know what we want in the first place

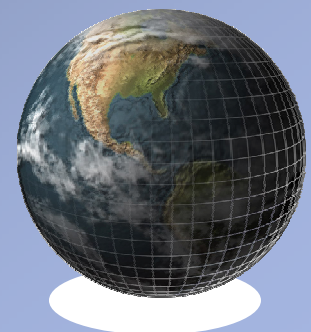
Social Decision Making

- Our response is frequently to look at what other people are doing
- Call this “social decision making”
- Often quite adaptive
  - Often, other people *do* know something (ecologically rational)
  - Also, we won’t do any worse than neighbors (social comparison)
- But sometimes, strange things can happen



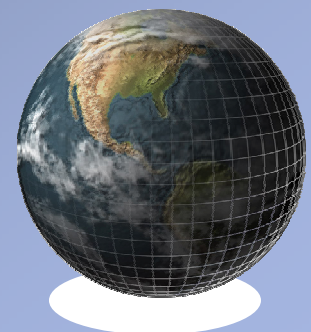
Information Cascades

- When everyone is trying to make decisions based on the actions of others, collectives may fail to aggregate information
- Small fluctuations from equilibrium can lead to giant cascades
  - Bubbles and crashes the stock market
  - Fads and skewed distributions in cultural markets
  - Sudden explosions of social unrest (e.g. East Germany, Indonesia, Serbia)
  - Changes in previously stable social norms
  - “Celebrity effect” (someone who is famous principally for being well-known)



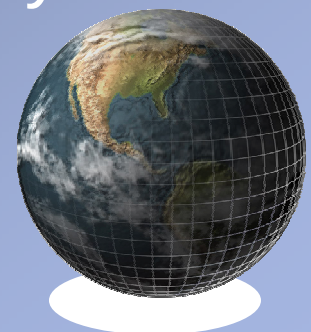
Cascades on Networks

- If it matters so much that people pay attention to each other…
- Must also matter specifically who is watching whom
- Nor do we watch everyone equally
- Structure of this “signaling network” can drive or quash a cascade



Implications of Cascades

- Dynamics very hard to predict
  - Each decision depends on dynamics/history of previous decisions (which in turn depend on prior decisions)
- Cascade is a function of globally-connected "vulnerable cluster"
- Connectivity matters, but in unexpected ways
  - Vulnerable nodes actually *less* well connected
  - Opinion leaders / Connectors not the key
- Group structure may increase vulnerability
- Successful stimuli are identical to unsuccessful



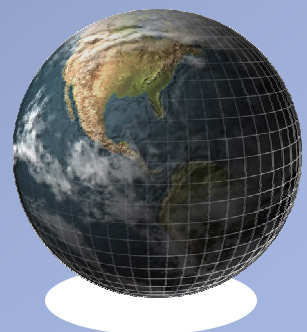
Implications Continued…

- Outcome can be unrelated to either
  - Individual preferences (thresholds), or
  - Attributes of “innovation”
- Implies that retrospective inference is problematic
  - Self-reported reasons may be unreliable
  - Timing of adoption may be misleading
  - Conclusions about quality (or even desirability) may be baseless
- “Revealed preferences” might be misleading
  - What succeeds may not be “what market was looking for”

Some (philosophical) problems

- If our actions don't reveal our intrinsic preferences and the outcomes we experience don't reflect our intrinsic attributes, then
  - How do we judge quality, assign credit, etc?
  - In what sense do attributes and preferences define an "individual"?
- Networks suggest need for new notion of individuality

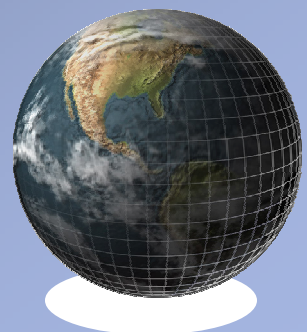
  "All decisions are collective decisions, even individual decisions"



These are hard questions: Can we figure them out?

- Networks lie on the boundaries of the disciplines
- Physicists, sociologists, mathematicians, biologists, computer scientists, and economists can all help, and all need help
- Interdisciplinary work is hard for specialists

- Jury is still out, but there is hope…perhaps the Science of Networks will be the first science of the 21st Century



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(W. W. Norton, 2003)

Collective Dynamics Group

http://cdg.columbia.edu

Small World Project

http://smallworld.columbia.edu