Complex Networks: Small World Property

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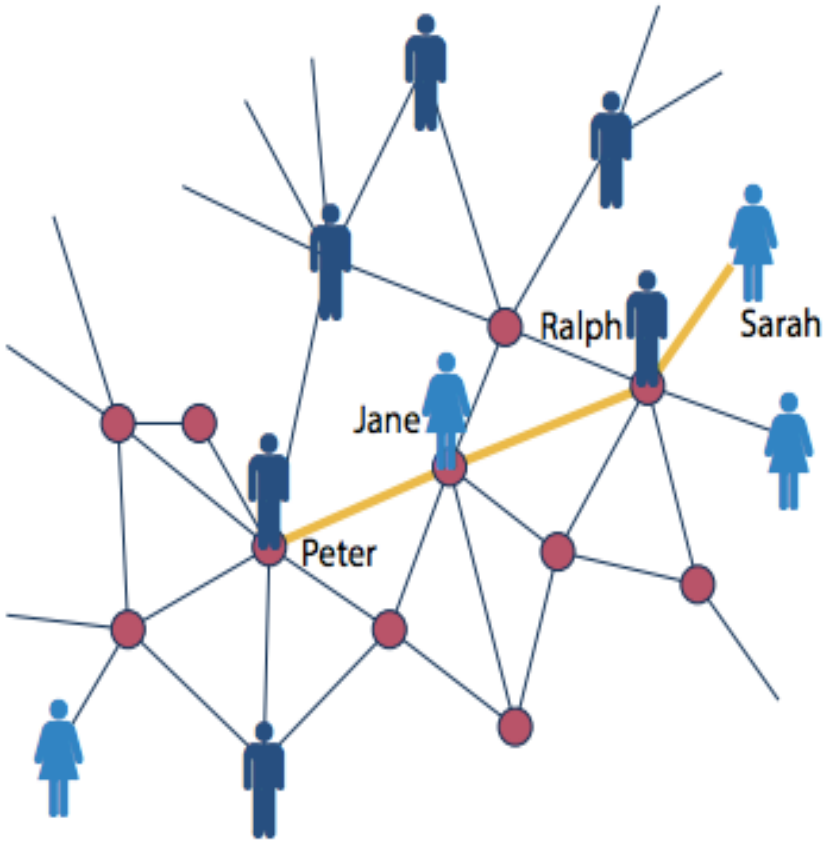
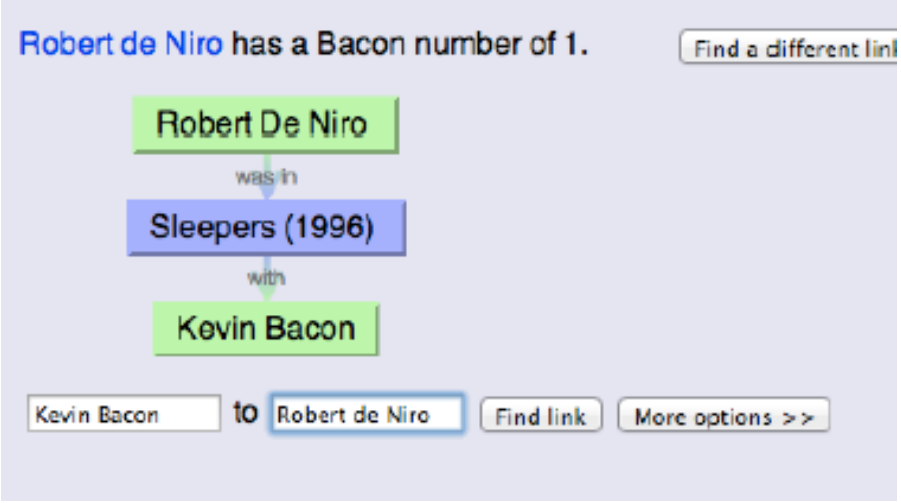


Image 3.9
Six degrees of separation.
According to six degrees of separation any two individuals, anywhere in

Network Science Book – Albert Barabasi



"it's a small world"

Small world phenomenon

- Also known as six degrees of separation
  - If you choose any two individuals anywhere on earth, you will find a mean path of six acquaintances between them

Small world phenomenon

- In other words …

The distance between two randomly chosen nodes in a network is surprisingly short

Small world phenomenon

- What does short (or small) mean, i.e. short compared to what?
- How do we explain the existence of these short distances?

Network Name	N	L	$\langle k \rangle$	$\langle d \rangle$	d_{max}	$\frac{\log N}{\log \langle k \rangle}$
Internet	192,244	609,066	6.34	6.98	26	6.59
WWW	325,729	1,497,134	4.60	11.27	93	8.32
Power Grid	4,941	6,594	2.67	18.99	46	8.66
Mobile Phone Calls	36,595	91,826	2.51	11.72	39	11.42
Email	57,194	103,731	1.81	5.88	18	18.4
Science Collaboration	23,133	186,936	8.08	5.35	15	4.81
Actor Network	212,250	3,054,278	28.78	-	-	-
Citation Network	449,673	4,707,958	10.47	11.21	42	5.55
E Coli Metabolism	1,039	5,802	5.84	2.98	8	4.04
Yeast Protein Interactions	2,018	2,930	2.90	5.61	14	7.14

Table 3.2

Six degrees of separation.

The average distance $\langle d \rangle$ and the maximum distance d_{max} of the ten networks explored in this book. The last column provides $\langle d \rangle$ predicted by Eq. (19), indicating that it offers a reasonable approximation to $\langle d \rangle$. Yet, the agreement is not perfect - we will see in the next chapter that for many real networks Eq. (19) needs to be adjusted. For directed networks we list the average out-degree $\langle k_{out} \rangle$ and the path lengths are measured only along the direction of the links.

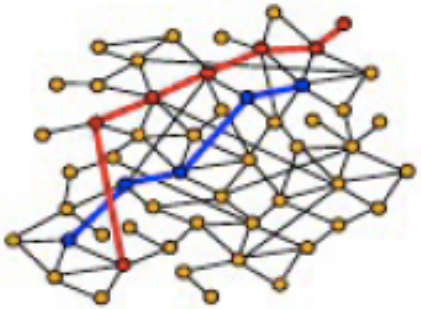
Network Science Book – Albert Barabasi

Small world experiment

- Stanley Milgram: 1967
- Targets
  - stock broker in Boston (MA)
  - student in Sharon (MA)
- Randomly selected residents
  - Wichita, Kansas, Omaha (Nebraska)
- Letter with:
  - Summary of the experiment
  - Photography, name, address and

  Information about the target person

Stanley Milgram

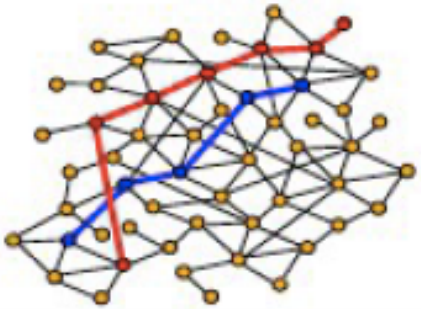


Small world experiment

- Residents were asked to forward the letter to a friend, relative or acquaintance, who is more like to know the target person

"I (Milgran) asked a person of intelligence how many steps the thought it would take, and he said that it would require 100 intermediate persons, or more, to move from Nebraska to Sharon"

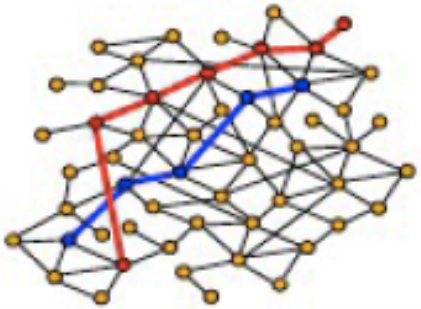
Stanley Milgram



Small world experiment

- After few days, the first letter arrived: only 2 hops!
- 42 of the 160 letters made it back, some requiring close to a dozen intermediates
- Completed chains: number of intermediates was 5.5!

Stanley Milgram



Small world experiment

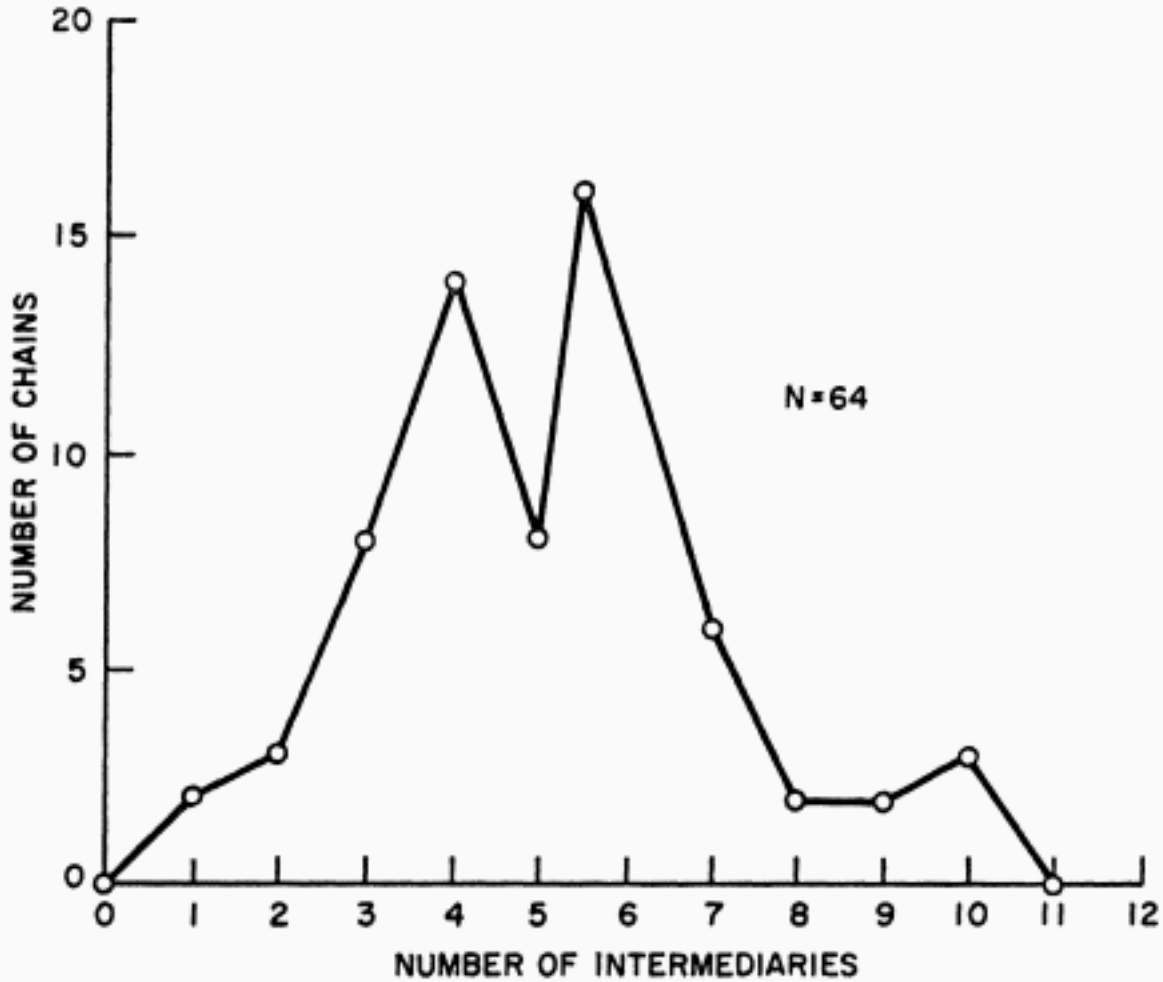
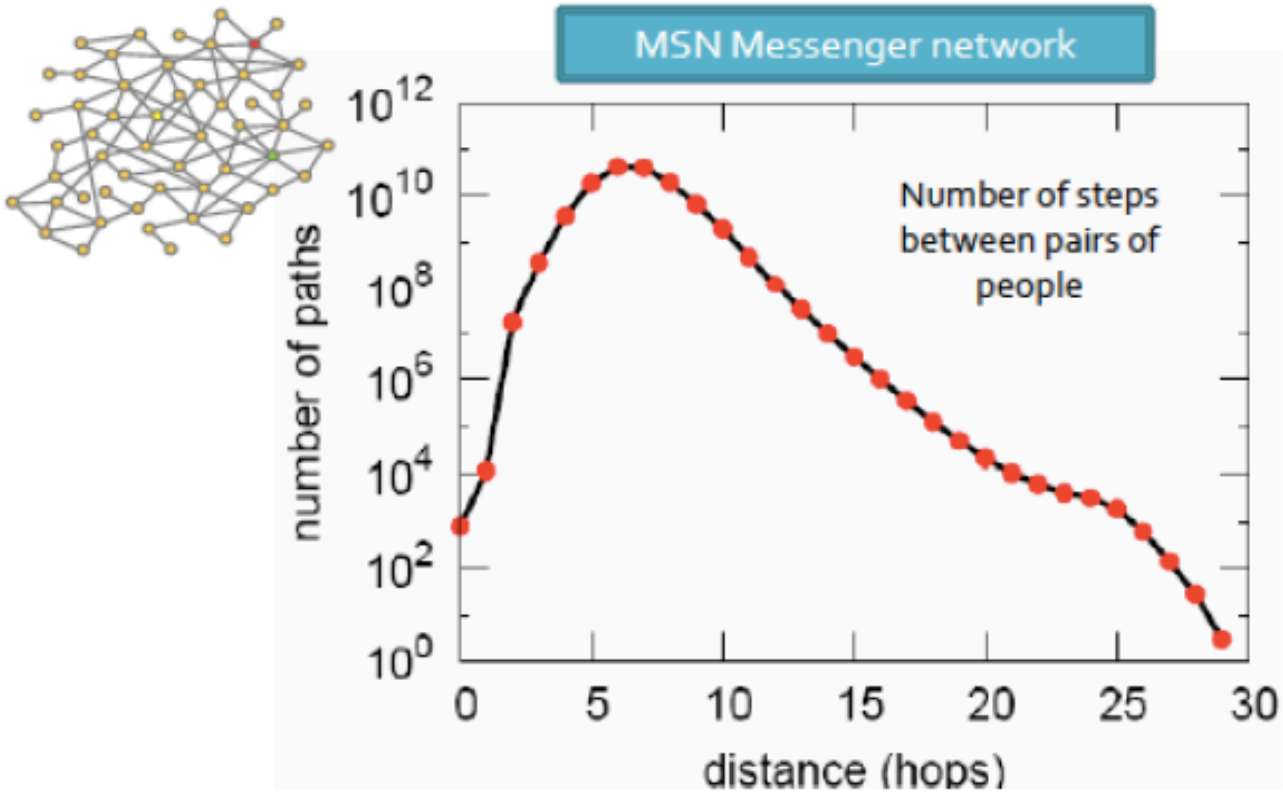


FIGURE 1

Lengths of Completed Chains

Small world (MSN network)



90% of people can be reached in 8 hops

Mean Shortest Path: 6.6 hops

Six degrees of separation

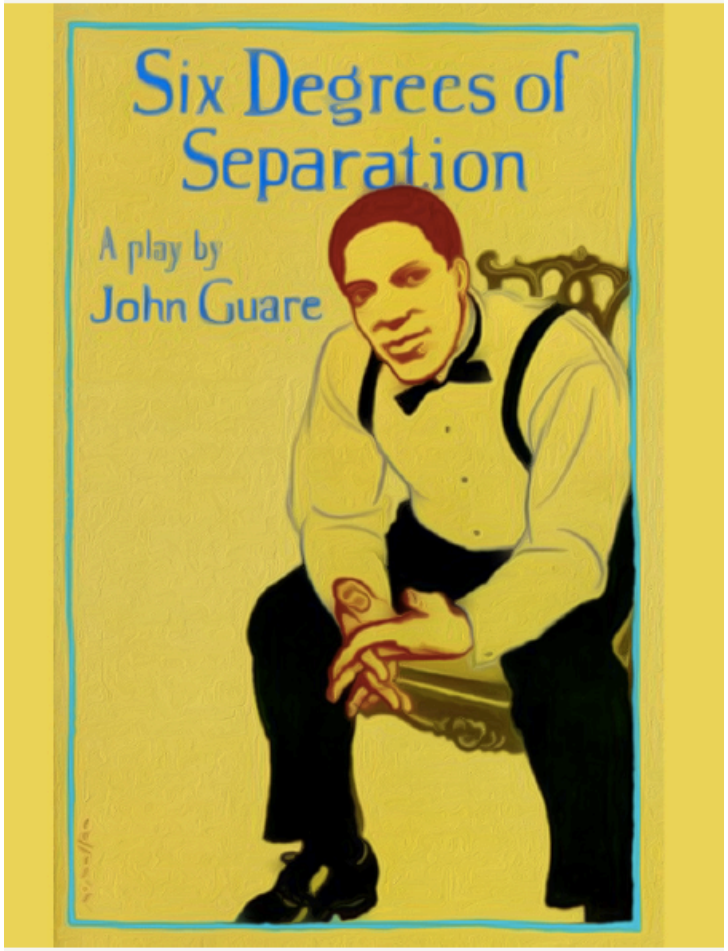


Image 3.14

Six Degrees of Separation.

Cover of John Guareís Six Degrees of Separation play, that helped turn six degrees into a catch phase of popular culture.

Network Science Book – Albert Barabasi

Six degrees of separation

The phrase "six degrees of separation" was introduced in 1991 by the playwright **John Guare**, who used it as the title of his Broadway play, later turned into a movie. The play's lead character, Ousa, musing about the world's interconnectedness, tells her daughter:

"Everybody on this planet is separated by only six other people. Six degrees of separation. Between us and everybody else on this planet. The president of the United States. A gondolier in Venice. It's not just the big names. It's anyone. A native in a rain forest. A Tierra del Fuegan. An Eskimo. I am bound to everyone on this planet by a trail of six people. It's a profound thought. How every person is a new door, opening up into other worlds."

Milgram's study was confined to the United States, linking individuals in Wichita and Omaha to Boston. Guare, however, with the sweep of a writer's imagination, generalized six degrees to the whole planet, bringing it closer in spirit to Karinthy's 1929 description. As more people watch movies than read sociology papers, Guare's version prevailed in popular thought.

Network Science Book – Albert Barabasi

Six degrees of separation

Six degrees of separation: Kevin Bacon

- Game created on 1994
- Network of Hollywood stars
  - Two actors are linked together if they were at the same movie
- Bacon Number: total number of hops until reach Kevin Bacon

Six degrees of separation: Kevin Bacon

But why use Kevin Bacon as the "center" of the Hollywood universe? It all started when three college friends, Brian Turtle, Mike Ginelli, and Craig Fass, were snowed in one night watching movies on TV. *Footloose* was followed by *Quicksilver*, with a commercial for a third Kevin Bacon movie coming on between the other two. This impromptu Kevin Bacon marathon caused the three friends to remark on the multitude of movies which included Bacon. It seemed like he was in everything! This prompted the question: Had Bacon ever worked with Robert De Niro? This was before the movie *Sleepers* had been released, so the answer was no. However, De Niro was in *The Untouchables* with Kevin Costner, who was in *JFK* with Bacon. And so the game Six Degrees of Kevin Bacon was born.

Six degrees of separation: Kevin Bacon

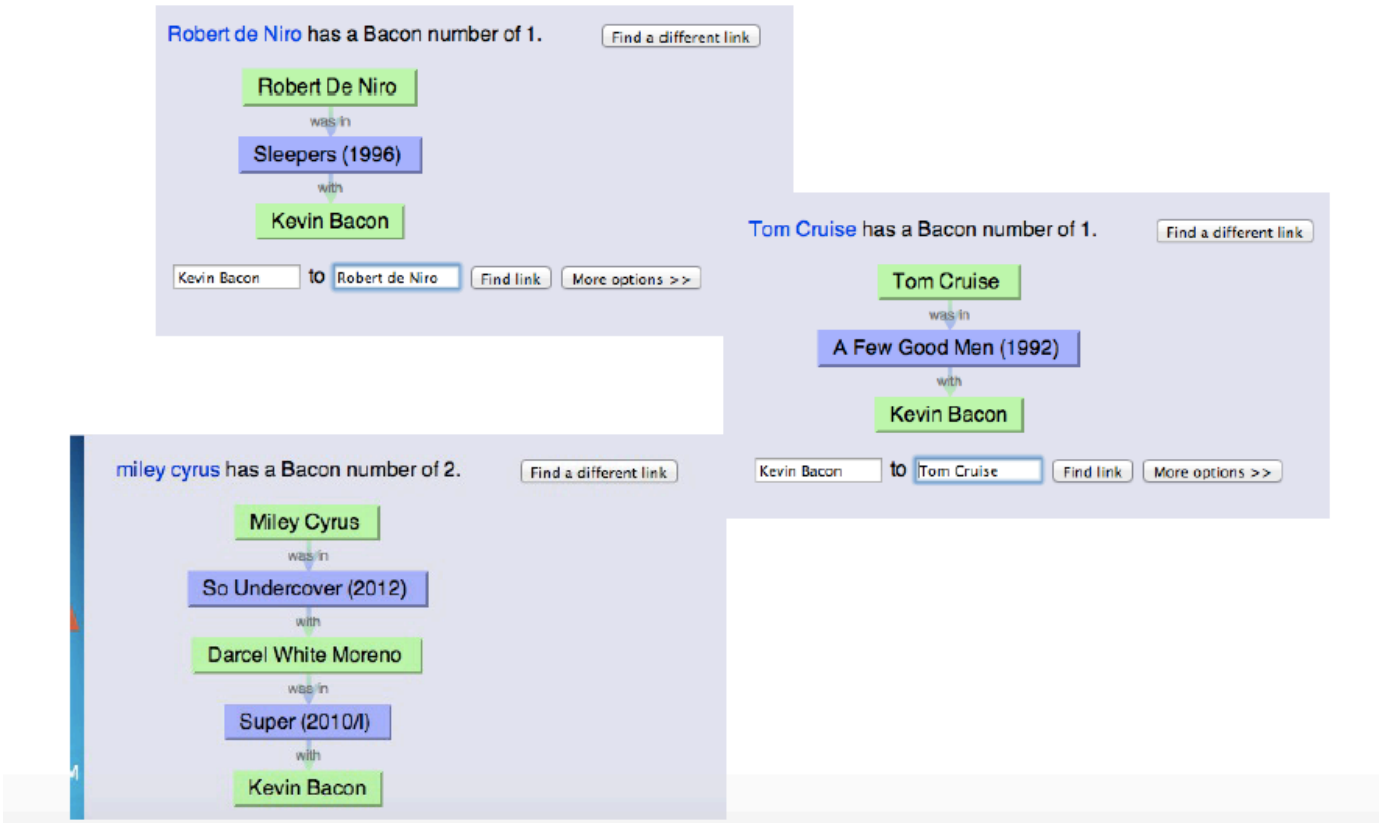
- Most paths: 6 or less hops
- 329 of the 1605485: 7 or more hops
- Only 12% of actors are not connected to Kevin Bacon

Six degrees of separation: Kevin Bacon

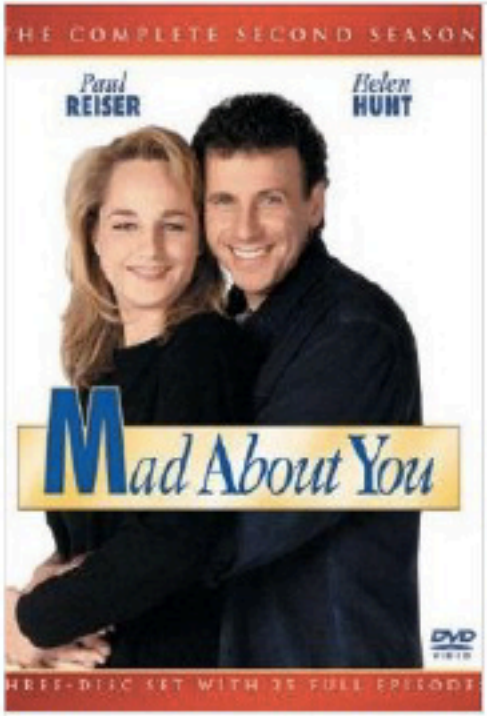
Bacon Number	# of people
0	1
1	2769
2	305215
3	1021901
4	253177
5	20060
6	2033
7	297
8	25
9	7

Six degrees of separation: Kevin Bacon

Six degrees of separation: Kevin Bacon



Six degrees of separation: Kevin Bacon



Contact the Show Creators on IMDbPro »

Mad About You: Season 5, Episode 7

More at IMDbPro »

Outbreak (19 Nov. 1996)

TV Episode - 22 min - Comedy | Romance

Your rating: ★★★★★★★★★★ -/10

7.6

Ratings: **7.6**/10 from 29 users

Reviews: write review

Paul & Jamie decide to announce they are pregnant on Thanksgiving. Jamie tells a stranger on Monday. Ira figures it out on Tuesday who tells the hair dresser, who tells Lisa, who tells Sanford, and it continues. It's the Kevin Bacon game.

Director: David Steinberg

Writers: Danny Jacobson (created by), Paul Reiser (creator), 1 more credit »

Stars: Paul Reiser, Helen Hunt, Leila Kenzle | See full cast and crew »

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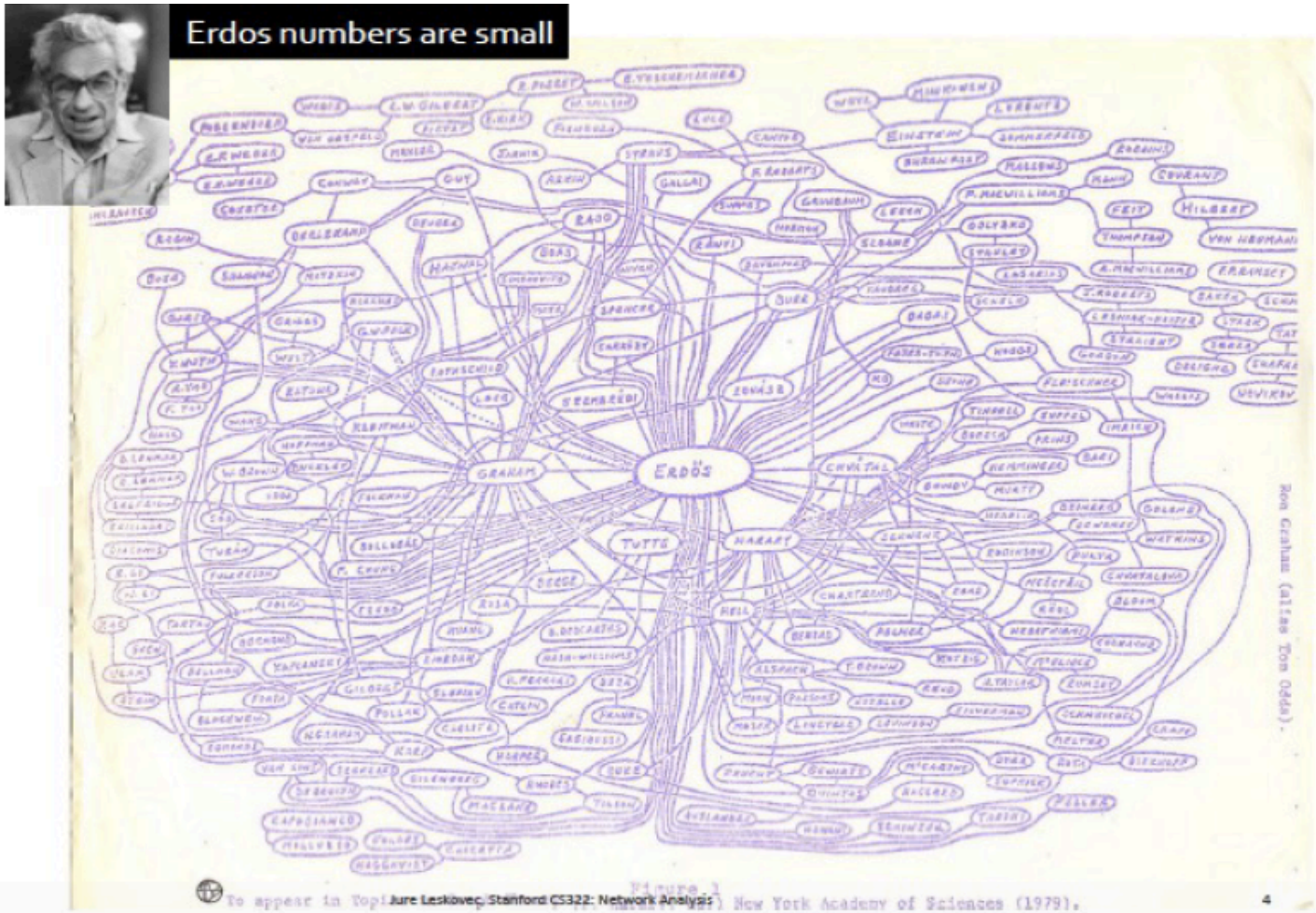
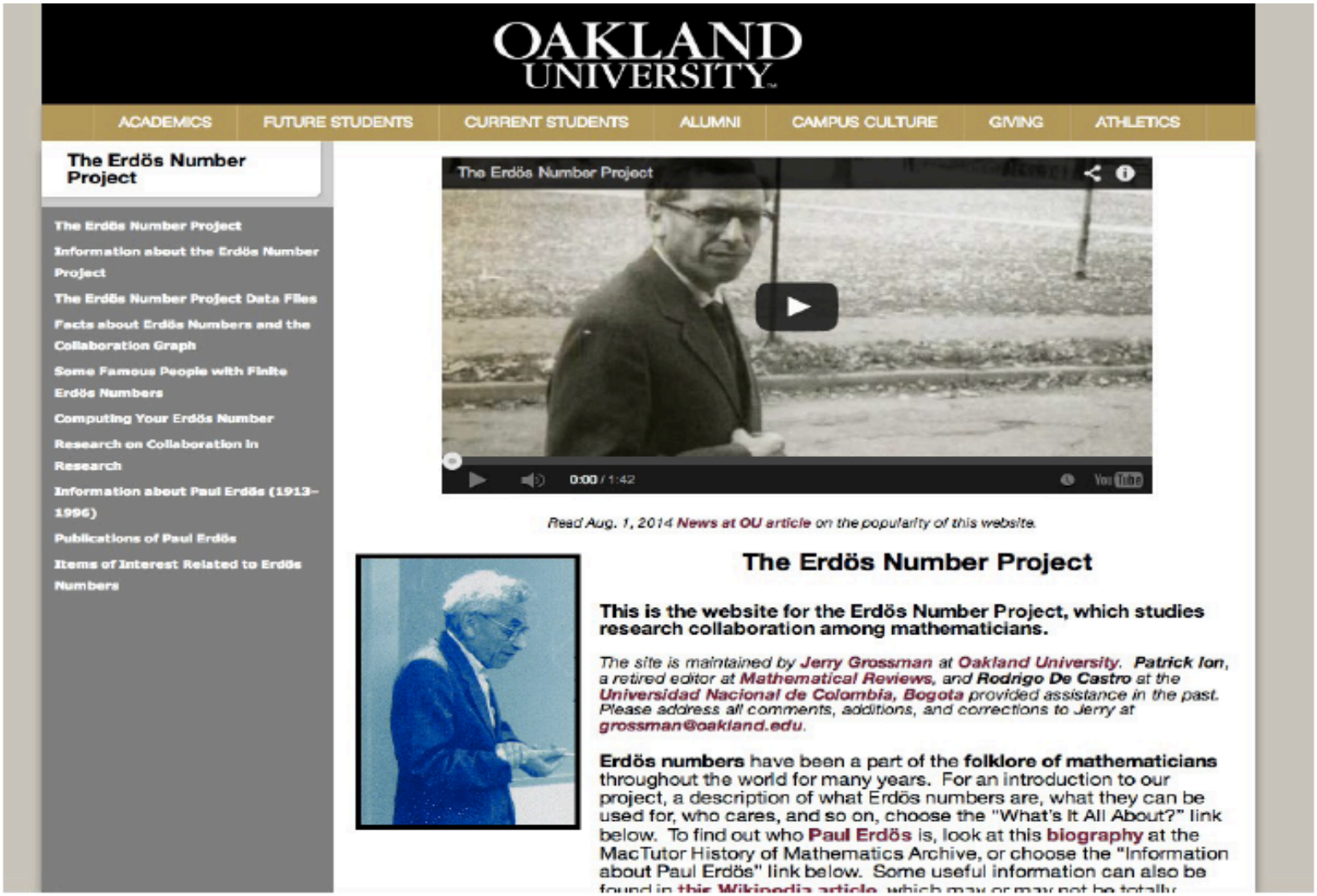
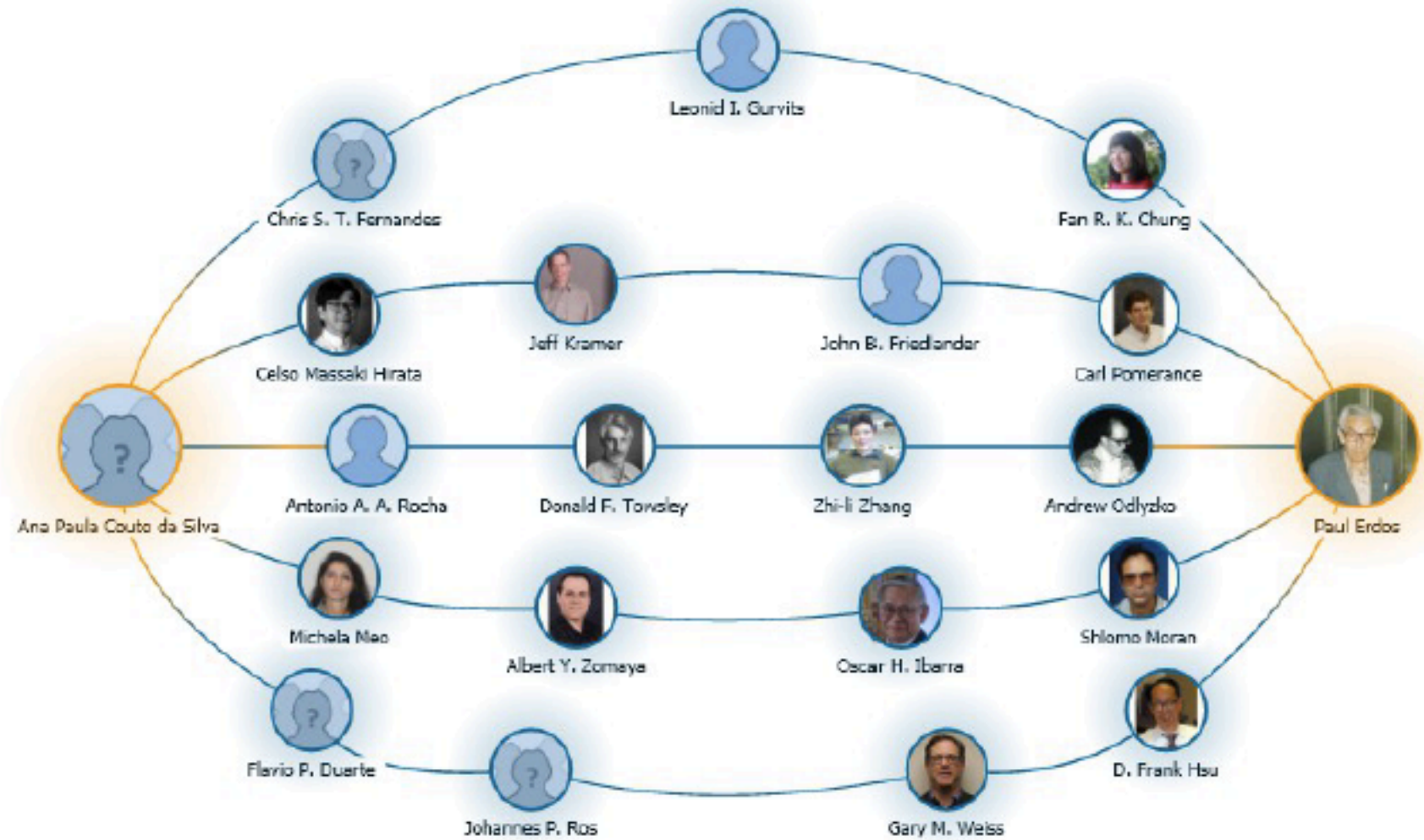
Six degrees of separation: Erdos Number



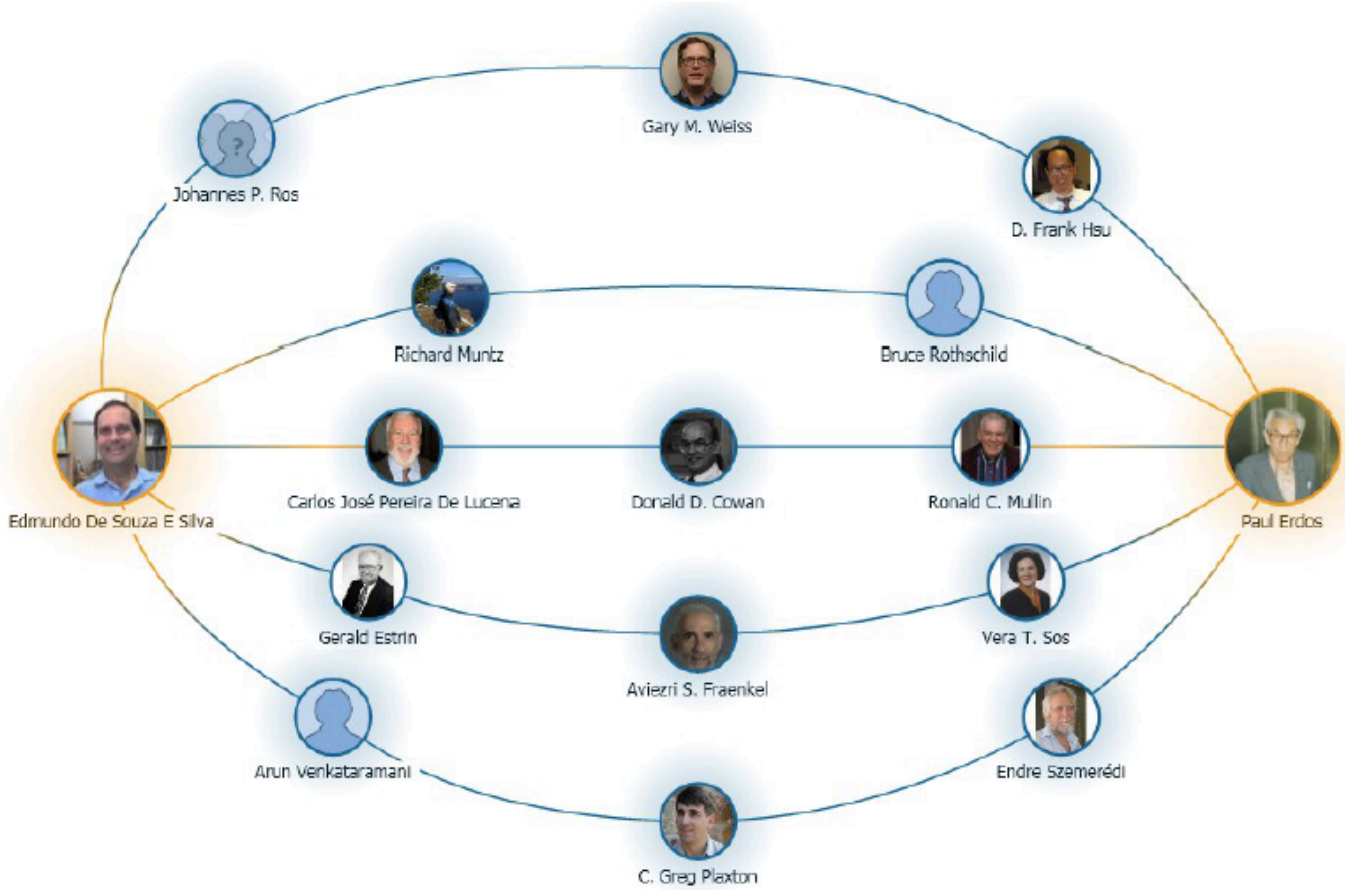
Six degrees of separation: Erdos Number



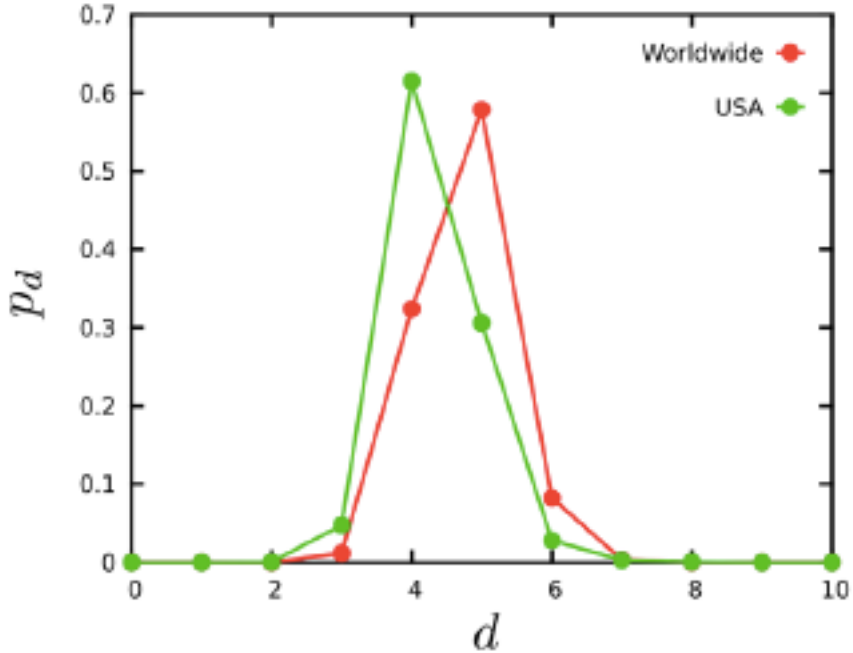
Six degrees of separation: Erdos Number



Six degrees of separation: Erdos Number



Six degrees ?
Facebook finds only four! (2011)



Network Science Book – Albert Barabasi

Revisiting Milgram experiment

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REPORT

An Experimental Study of Search in Global Social Networks

Peter Sheridan Dodds[1], Roby Muhamad[2], Duncan J. Watts[1,2,*]

+ Author Affiliations

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Revisiting Milgram experiment

Abstract

We report on a global social-search experiment in which more than 60,000 e-mail users attempted to reach one of 18 target persons in 13 countries by forwarding messages to acquaintances. We find that successful social search is conducted primarily through intermediate to weak strength ties, does not require highly connected “hubs” to succeed, and, in contrast to unsuccessful social search, disproportionately relies on professional relationships. By accounting for the attrition of message chains, we estimate that social searches can reach their targets in a median of five to seven steps, depending on the separation of source and target, although small variations in chain lengths and participation rates generate large differences in target reachability. We conclude that although global social networks are, in principle, searchable, actual success depends sensitively on individual incentives.

P. Dodds, R. Muhamad, D. Watts, An experimental study of search in global social networks, 2003

Connected : The Power of Six Degrees (2008)

Image 1.14
Connected.

The trailer of the award winner document *Connected*, directed by Annamaria Talas, focusing on network science.

http://www.imdb.com/video/wab/vi2571502361/

Some interesting references

The six degrees: Kevin Bacon at TEDx Midwest

https://www.youtube.com/watch?v=n9u-TITxwoM&nohtml5=False

1. J . Travers, S. Milgram, An Experimental Study of the Small World Problem, Sociometry, 1969
2. D. Watts and S. Strogatz, Collective dynamics of “small-world” networks, Nature, 1998
3. J.Kleinberg, Navigation in Small World, Nature, 2000
4. P. Dodds, R. Muhamad, D. Watts, An experimental study of search in global social networks, 2003
5. J. Kleinberg, The small-world phenomenon: An algorithmic perspective, 2000