Collaborative Problem-Solving and Network Structure

Tony Dekker

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Defence Science and Technology Organisation

Complex Adaptive Systems and Interacting Agents

Oxford, Sept 2006

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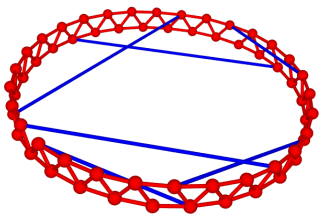
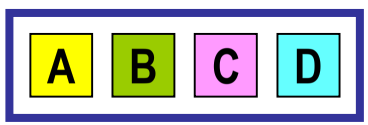
Overview of this talk

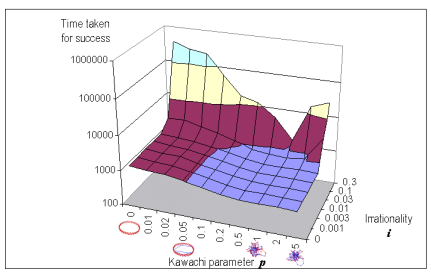
Context of the work



The Kawachi Process for “rewiring” graphs



A simple model of collaboration



Experimental results & conclusions

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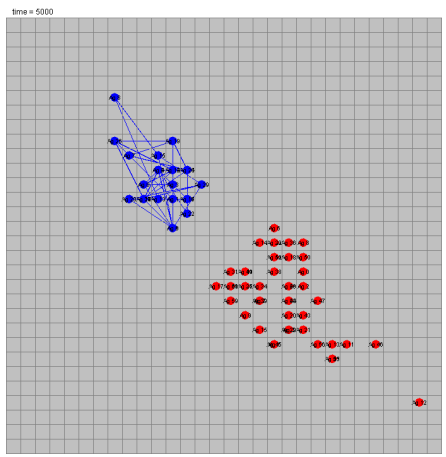
Context: need to find organisational structures which are effective under new and changing circumstances

Images from www.defence.gov.au/opcitadel/

Research Questions

- Which organisational structures are most effective?
- When does centralisation make sense?
- What is the impact of graph-theoretic properties such as average distance?



- We have begun to explore these questions with simulation studies: see www.acm.org/~dekker/orgnets.html

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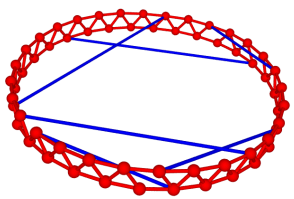
The Kawachi process is based on Watts

- Extends the **"Small World" network process** of Duncan Watts.

Complex 2004

- Developed by **Yuumi Kawachi** and presented at the 7th Asia-Pacific Conference on Complex Systems: *"The structural phase transition among fixed cardinal networks"* — See also www.mssanz.org.au/modsim05/proceedings/papers/dekker.pdf



- "Rewiring" replaces link $x - y$ (x of higher degree) by $x - z$ where z is chosen with probability proportional to 1 + degree.
- Repeat 10 times: "rewire" links with probability $p/10$.
- Need special treatment to avoid isolated nodes (improvement: maintain list of isolated nodes and prioritize reconnection).

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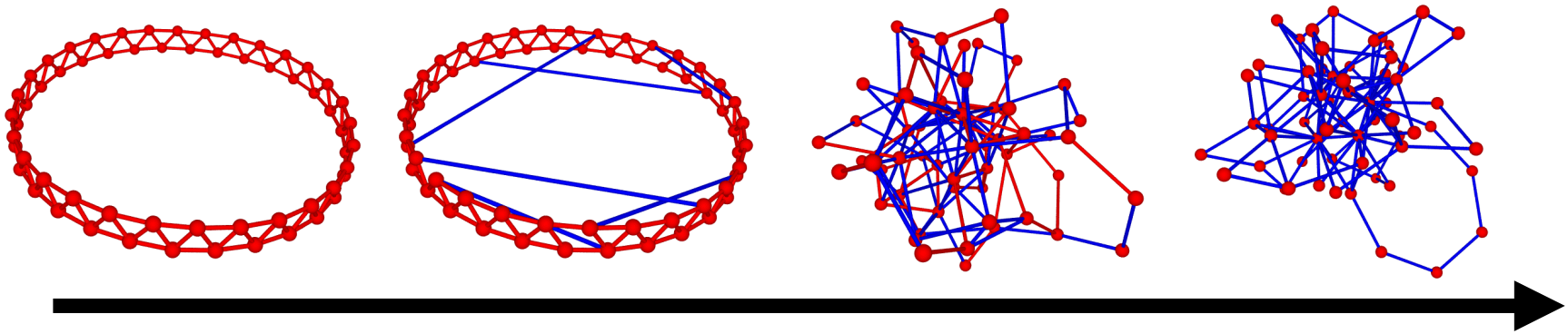
The Kawachi network process "rewires" links



$p = 0$	$p = 0.05$	$p = 1$	$p = 5$
Regular	**"Small-World"**	**Random** (approximately)	**"Scale-Free"**

- For small p, this is identical to the Watts "Small-World" process, since $1 - (1 - p/10)^{10}$ is approximately the same as p.
- For large p, the high-degree bias produces "Scale-Free" networks.

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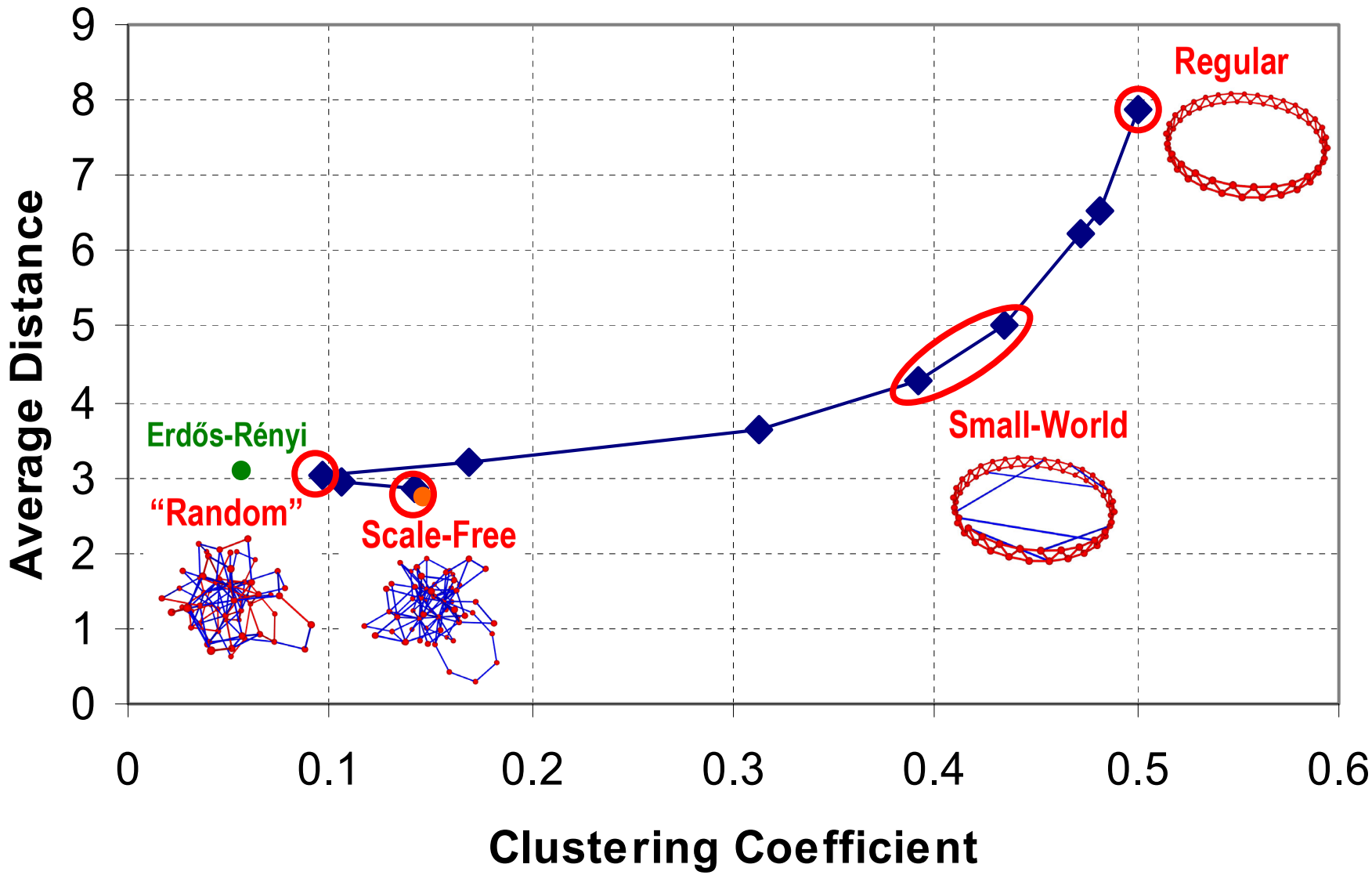
The Kawachi process produces 4 kinds of nets



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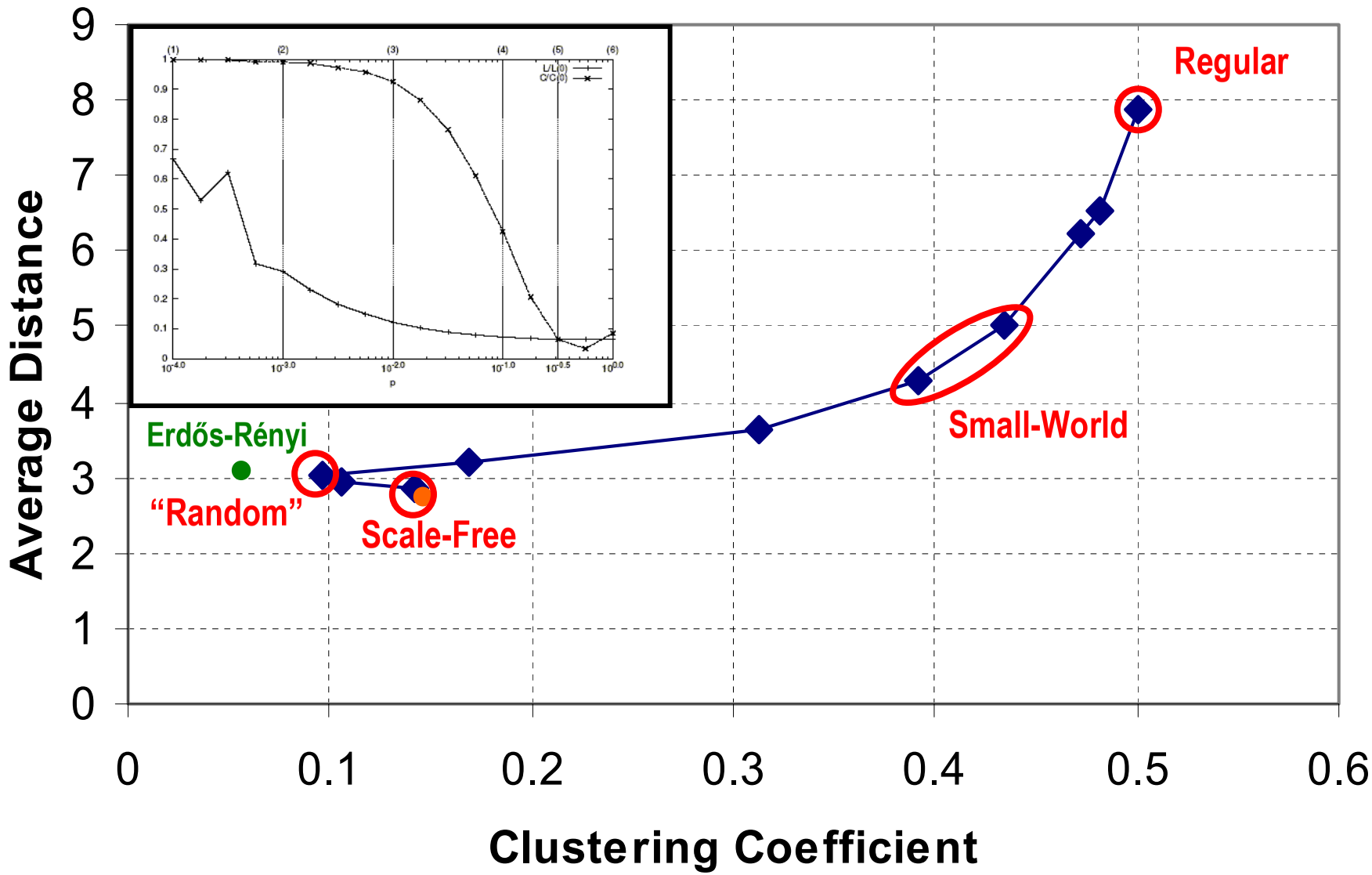
For larger n, the curve is steeper (Kawachi)



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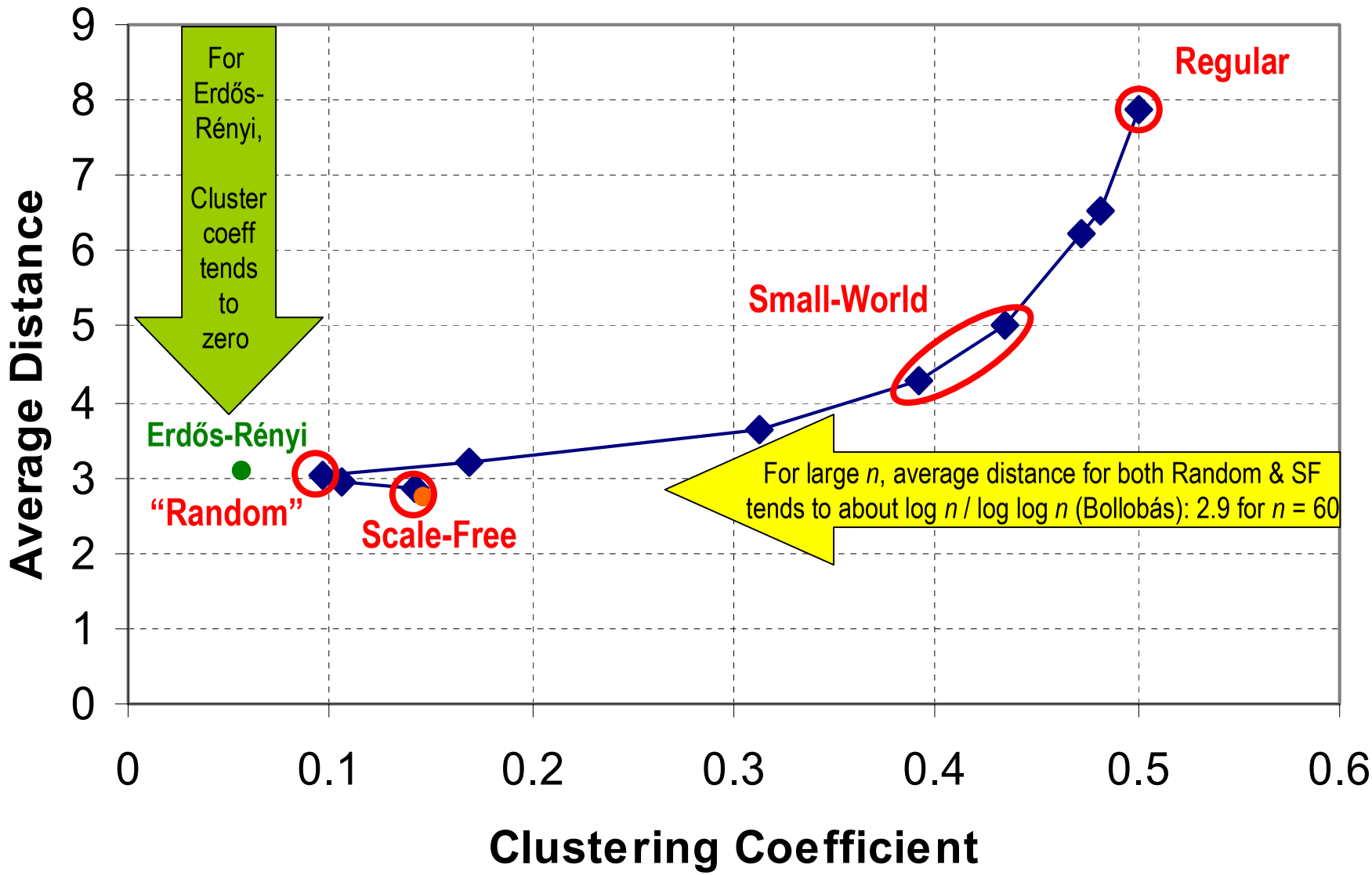
Average distance tends to log *n* / log log *n* …



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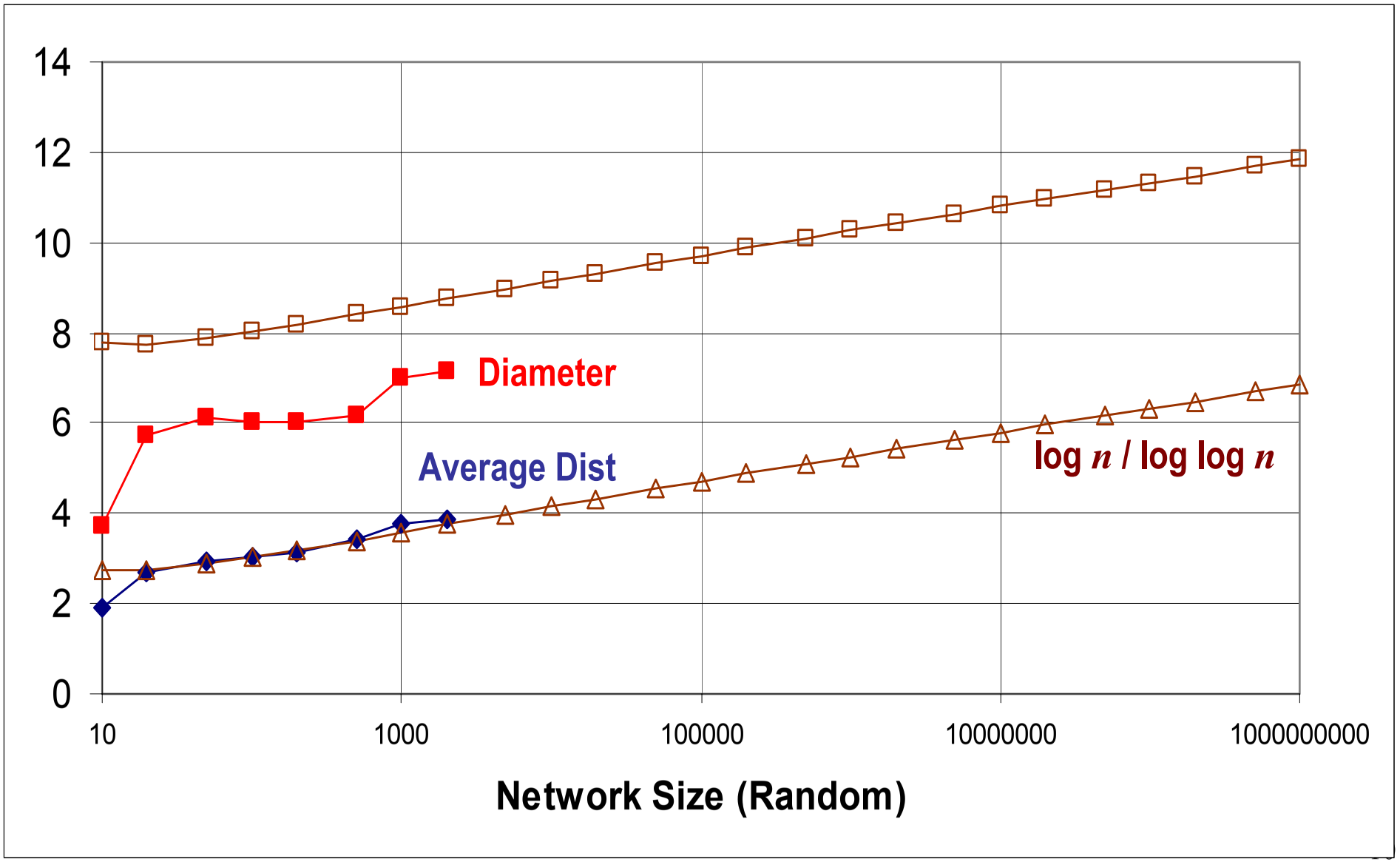
… up to +5, for random graphs (Chung & Lu)



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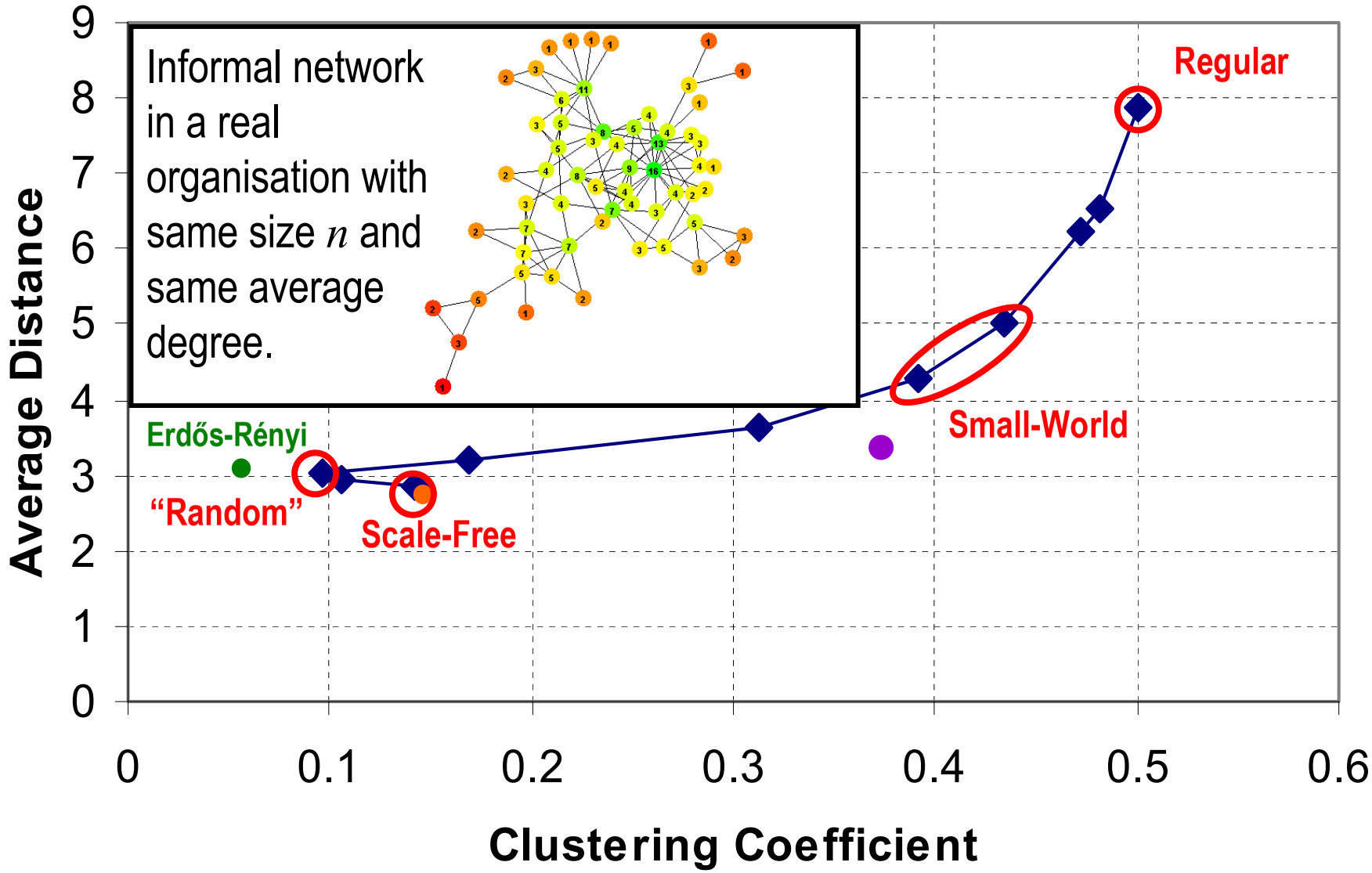
Real networks resemble Scale-Free networks



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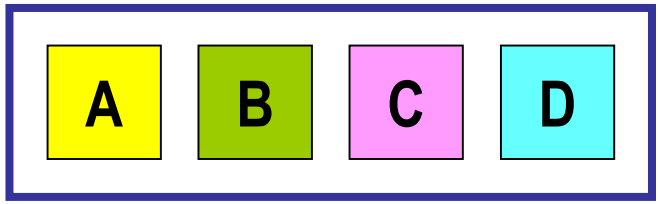
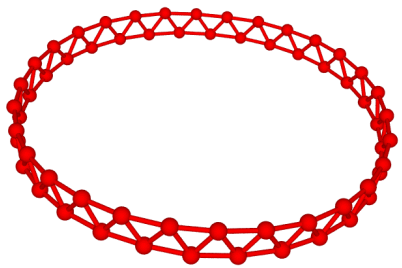
A simple model of networked collaboration …

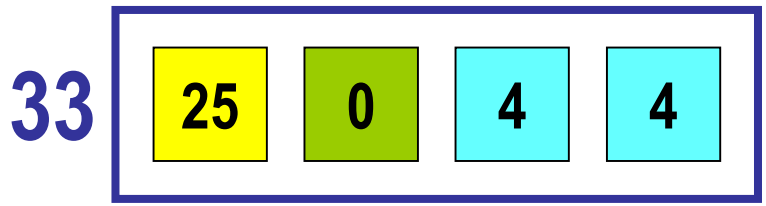


- Each node begins with **1** piece of information (possibly useless).
- Each node needs **4** appropriate pieces of information to succeed, so nodes must **exchange information**.



- Each node initially broadcasts its starting information, then the last useful piece of information it received.

… instantiated to numbers …



- Pieces of information are numbers 0…59
- Each node needs 4 perfect squares which add up to a **target number** 33…62.
- This is always possible if information is shared *(Lagrange)*
- Each node initially broadcasts its starting information, then the last useful piece of information it received.
- An agent **succeeds** if it finds the required numbers.

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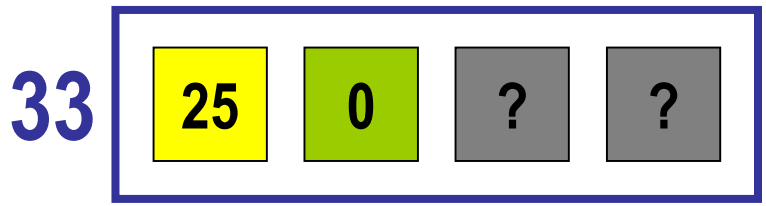
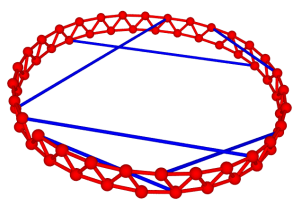
… and including irrationality



Useful = **Solves problem or creates new valid partial sums** (e.g. above 1 & 4 are useful, creating 26, 27, 29, 33)

Irrational = **Makes incorrect judgment about usefulness** — and therefore broadcasts a useless number (have a probability i that an agent is irrational)

Topology: 60-node network from Kawachi process (varying p)



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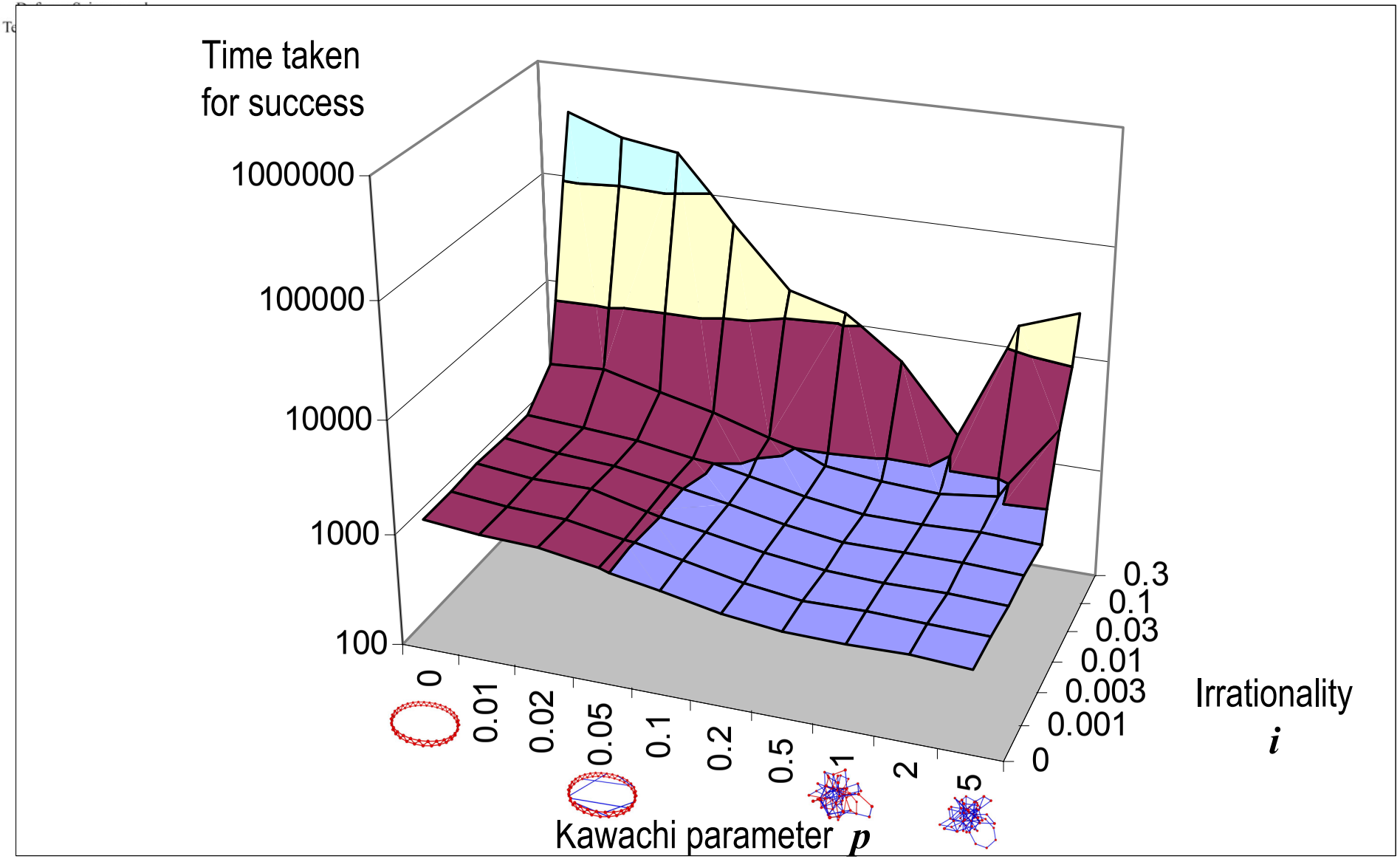
Time taken for solution depends on *i* and *p*



Simulation terminated at time 10,000: greater times estimated using no. of agents not succeeded

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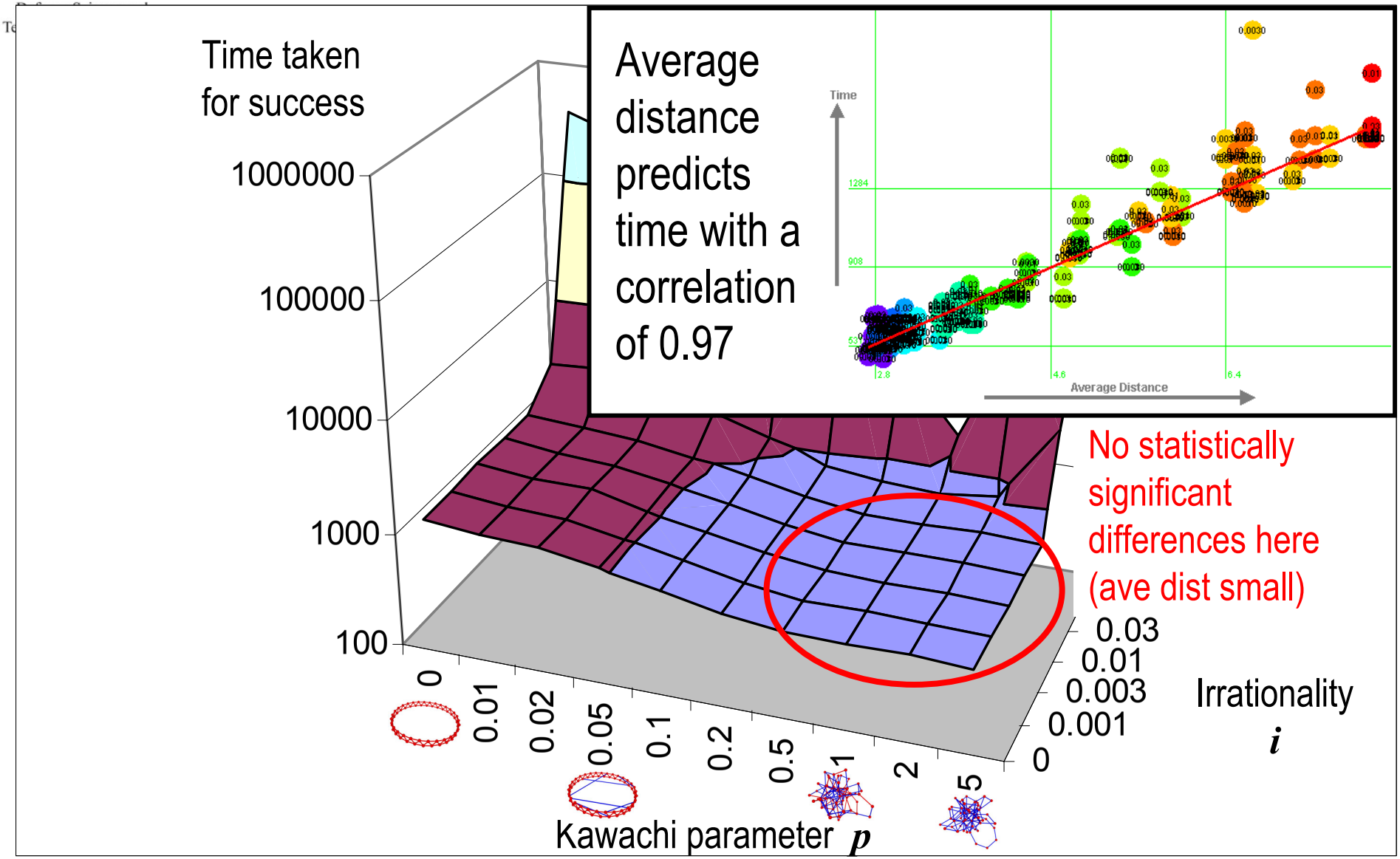
When rational (i < 0.1), time depends on ave dist



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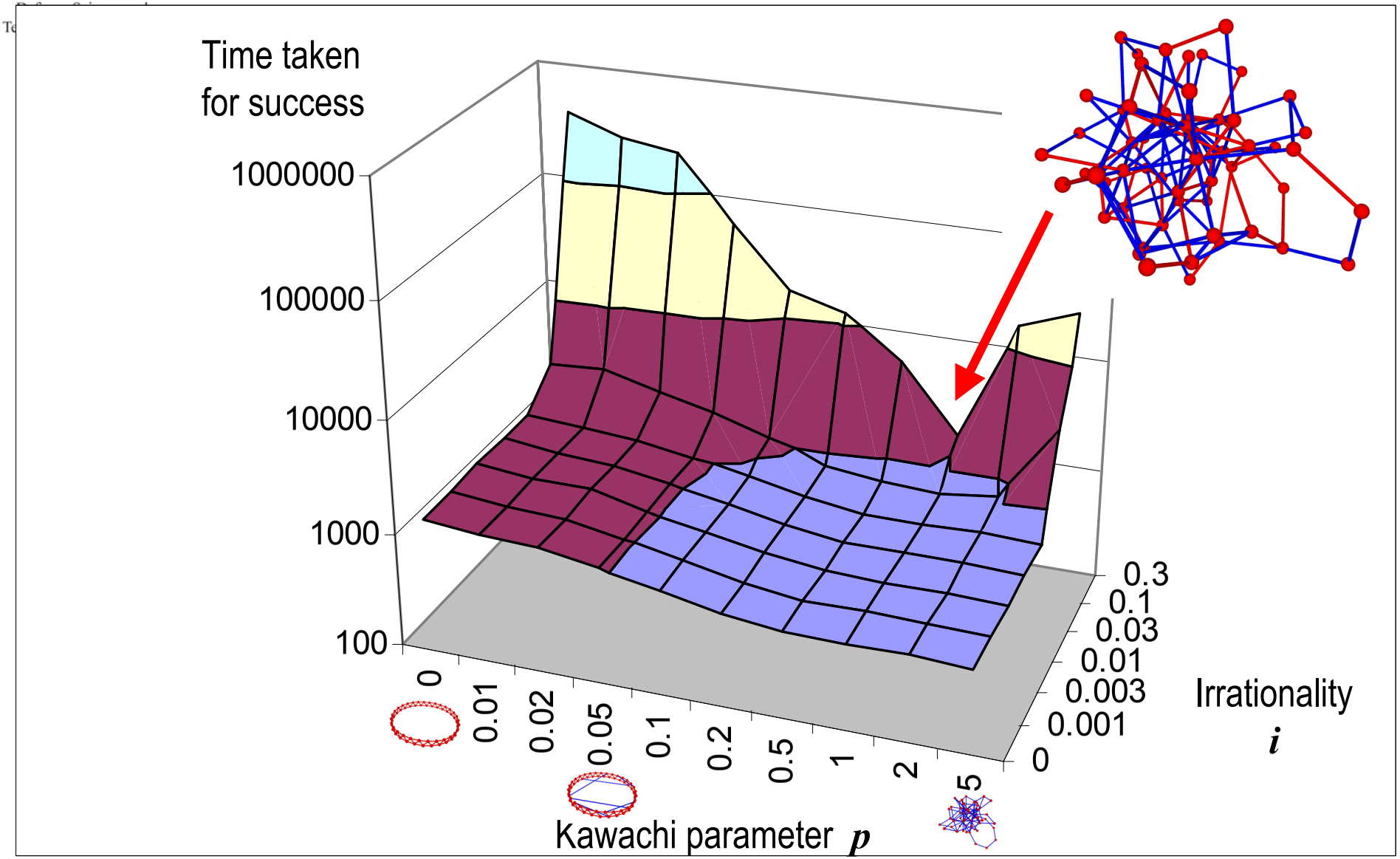
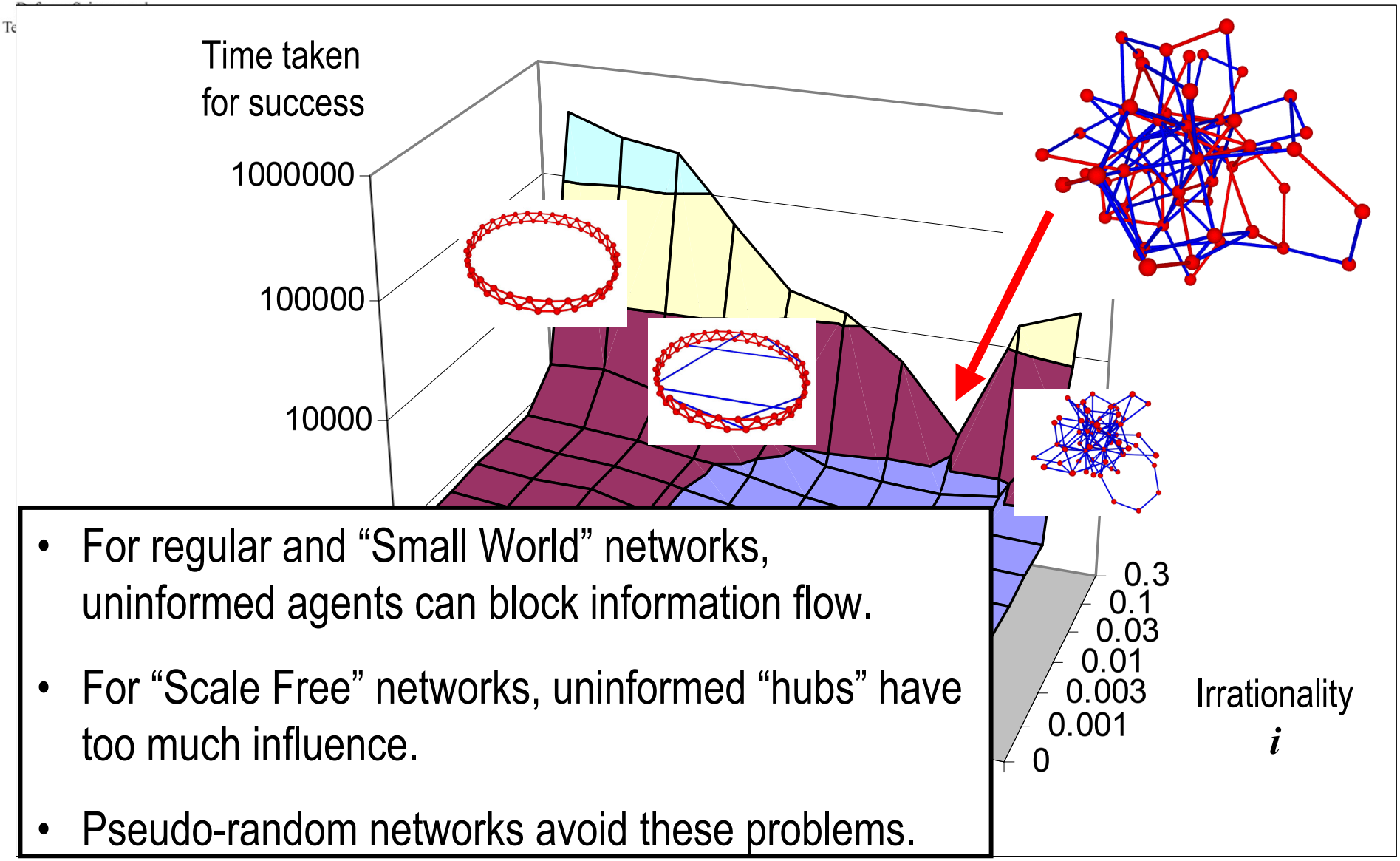
When irrational (i = 0.3) only "random" succeeds



Why is this so?



- For regular and “Small World” networks, uninformed agents can block information flow.
- For “Scale Free” networks, uninformed “hubs” have too much influence.
- Pseudo-random networks avoid these problems.

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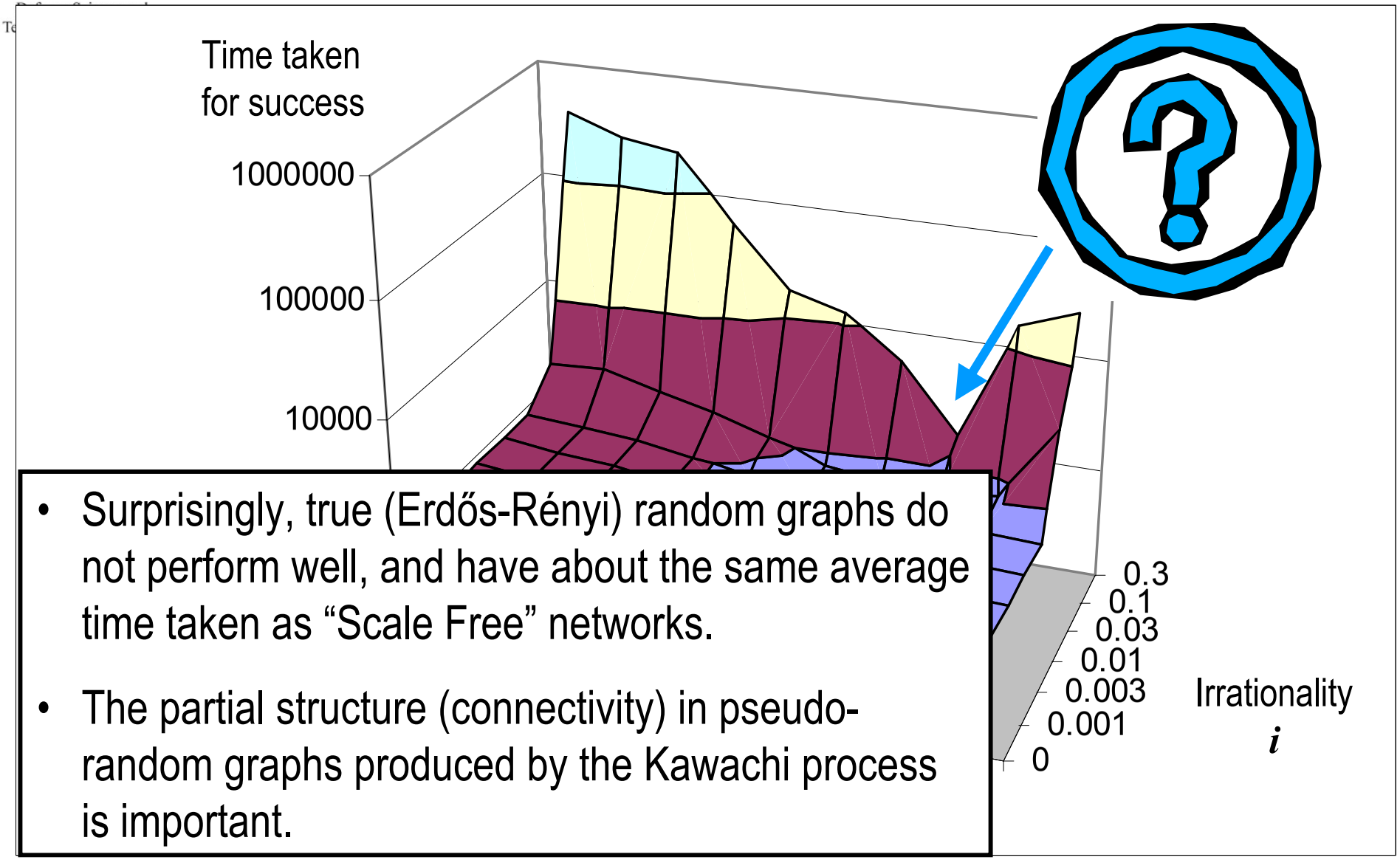
What about true (Erdős-Rényi) random graphs?



- Surprisingly, true (Erdős-Rényi) random graphs do not perform well, and have about the same average time taken as “Scale Free” networks.
- The partial structure (connectivity) in pseudo-random graphs produced by the Kawachi process is important.

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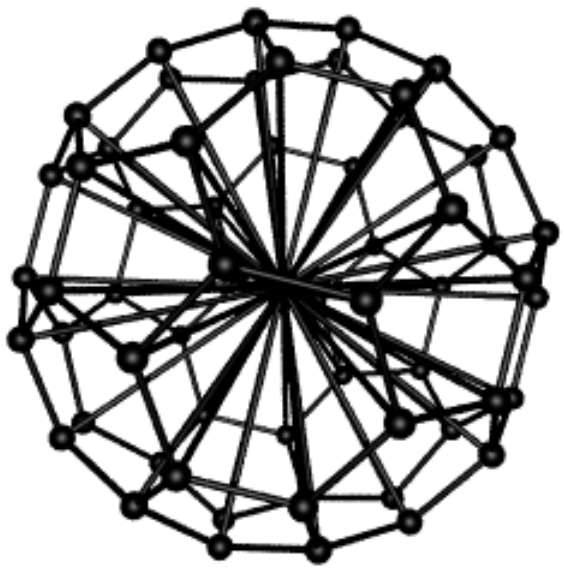
What about regular graphs?

- **Soccer ball with diagonals** has the same average degree
- But is regular
- Small average distance = 3.5
- Performs about as well as the "random" networks



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A comparison

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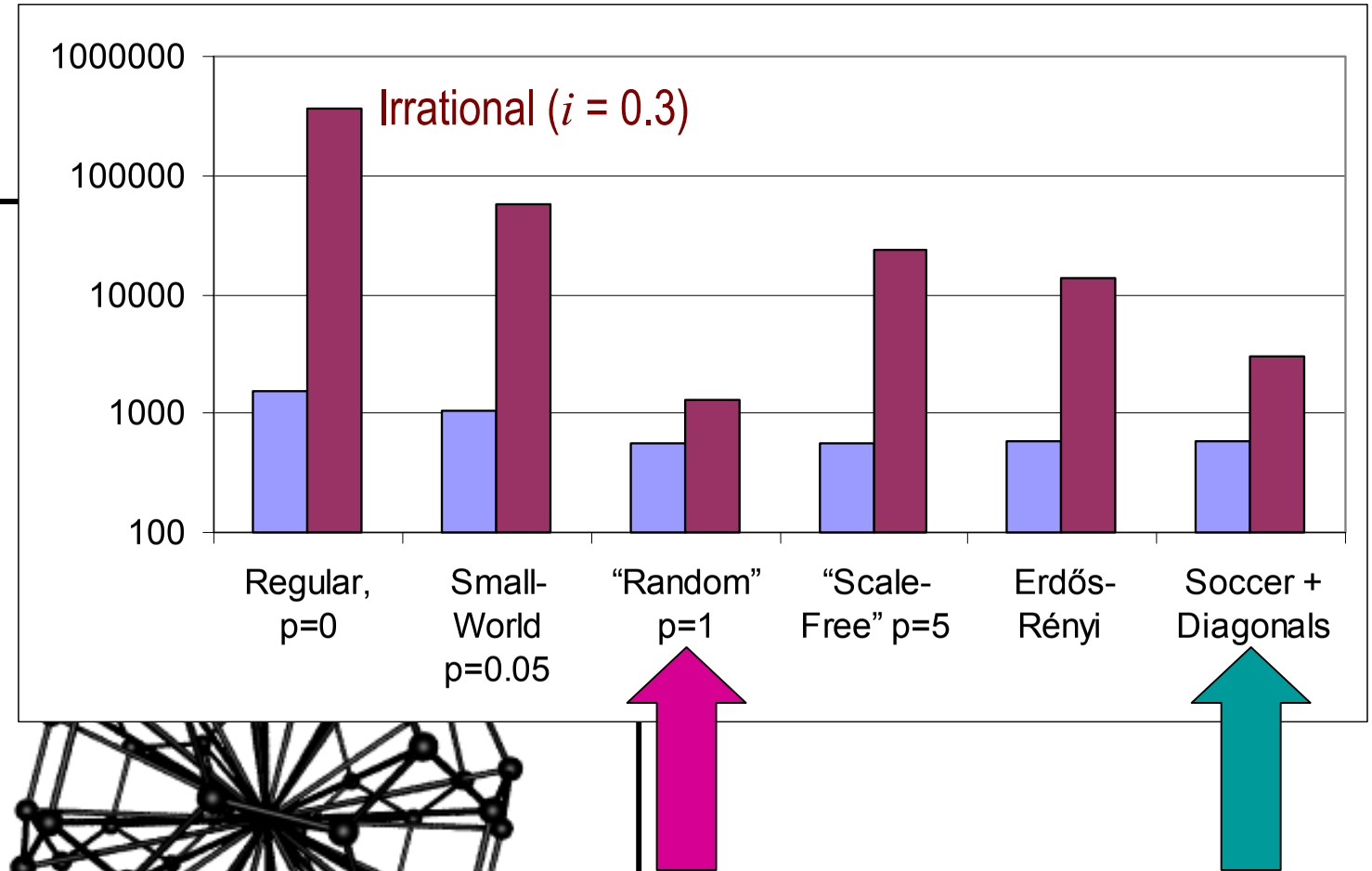

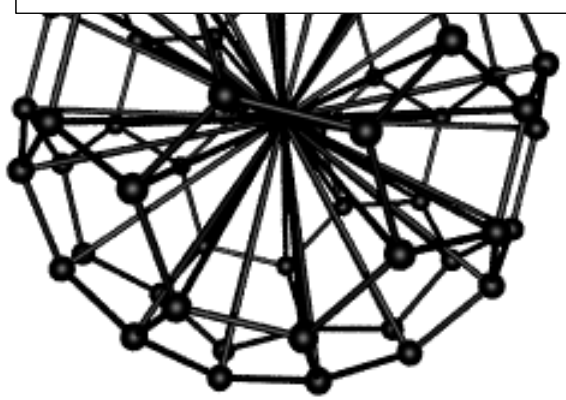

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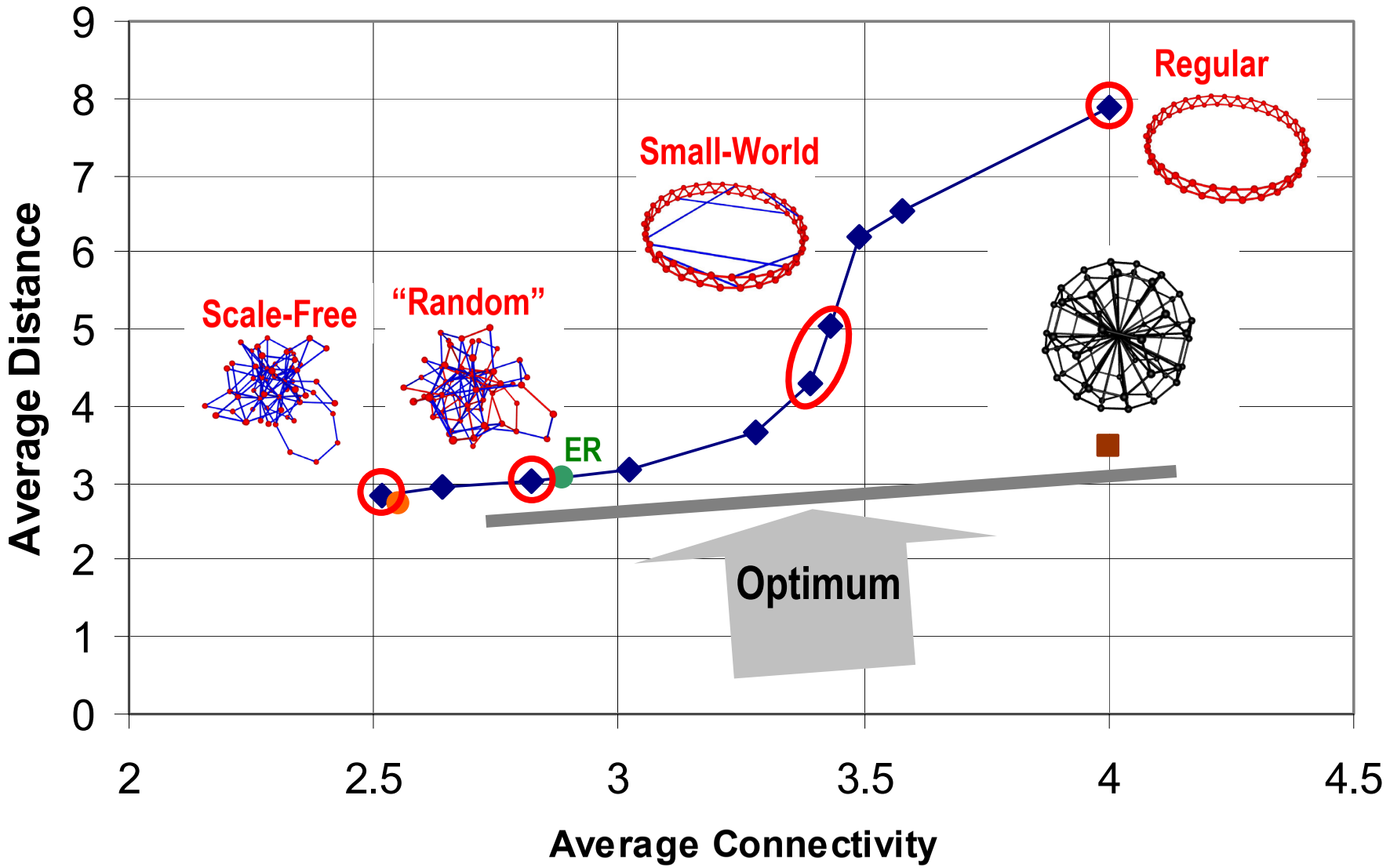
Long-Range Connectivity is Important



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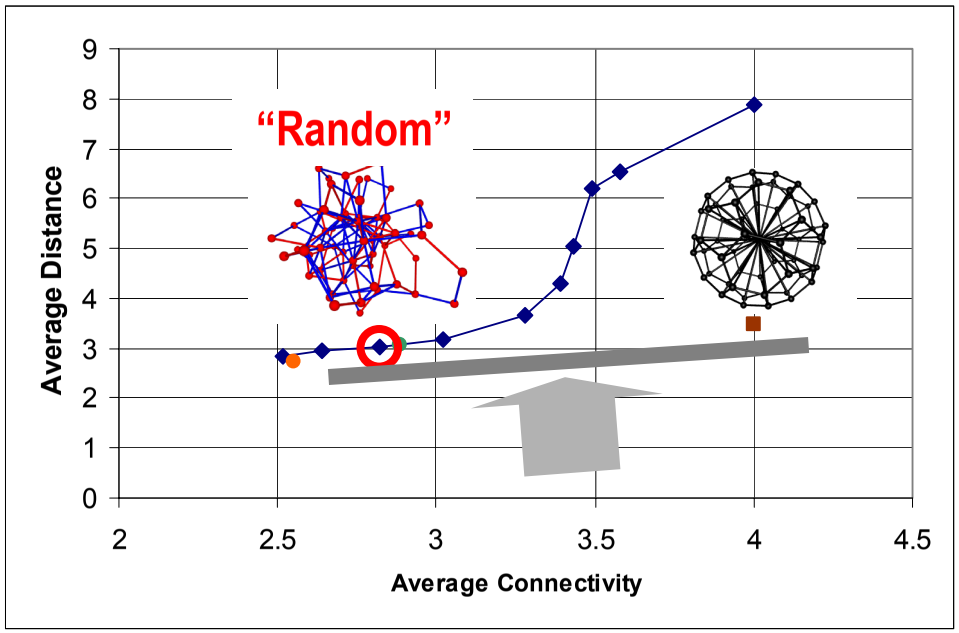
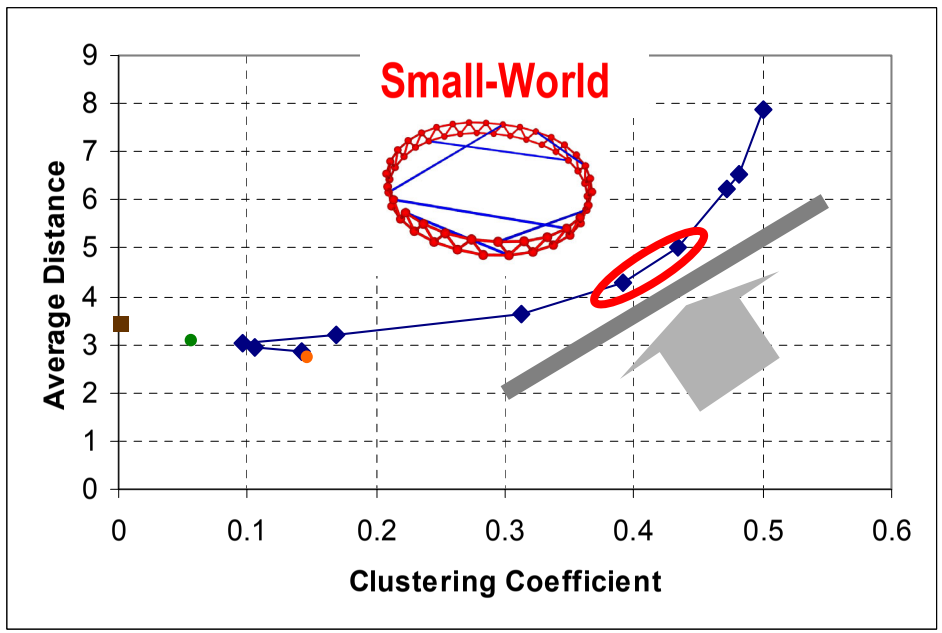
Average Connectivity *vs* Clustering Coefficient

Long Range



Short Range

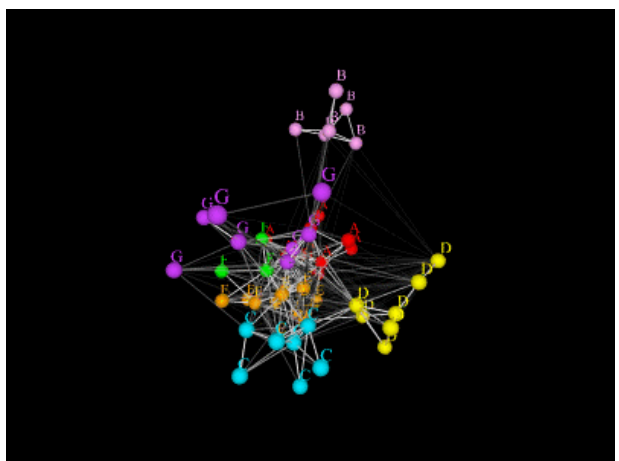


- **"Average Connectivity"** gives average number of independent paths between pairs of nodes
- Measures long-range connectivity
- **"Random"** and **"Soccer"** optimal

- **Clustering Coefficient** measures short-range connectivity
- **Small-World** networks provide optimal combination of low average distance and high clustering coefficient

Future work …

- Will further examine the key aspects of pseudo-random graphs.
- Have developed an **agent framework** with message-passing, planning, & neural-network learning.
- Intend to see if the superiority of pseudo-random graphs holds up for agents carrying out more realistic activities.
- Hope to relate this to empirical studies of informal social linkages in military organisations.



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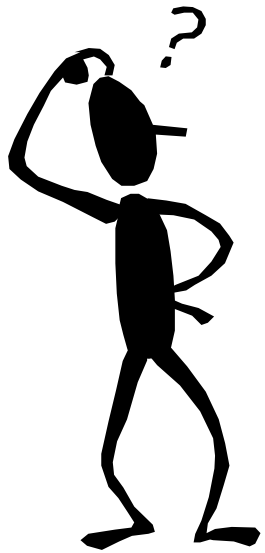
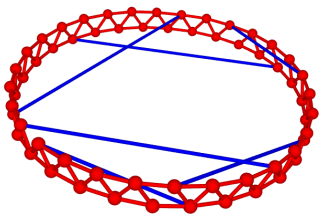
Any Questions?



Context of the work



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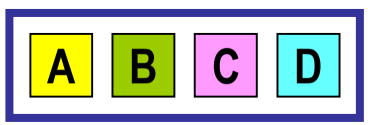

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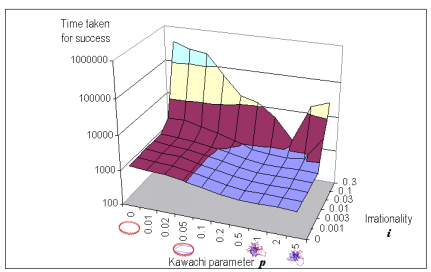

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