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Rich-Get-Richer Mechanism

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Principles of Complex Systems,
Vols. 1, 2, 3D, 4 Fourever, V for Vendetta

Deliverator: Calla Beauregard

Showrunner: Prof. Peter Sheridan Dodds

Computational Story Lab | Vermont Complex Systems Institute
University of Vermont | Santa Fe Institute



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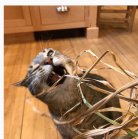
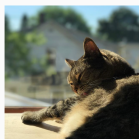
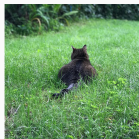
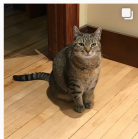
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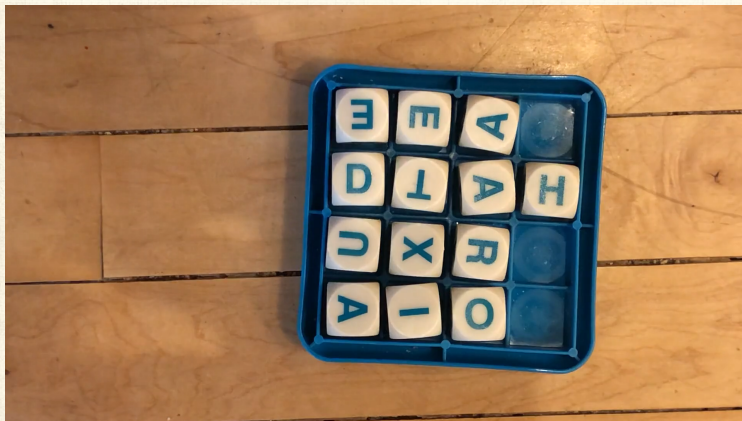
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The Boggoracle Speaks:



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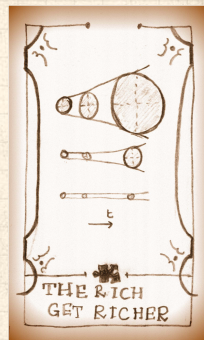
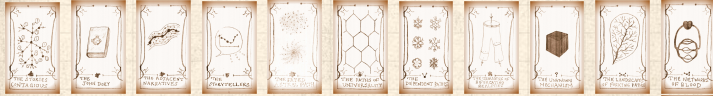
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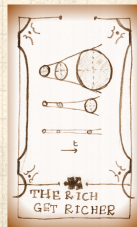
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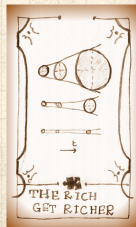
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Random walks represent **additive aggregation**



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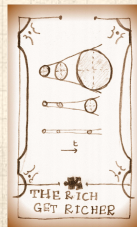
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Random walks represent **additive aggregation**



Mechanism: Random addition and subtraction



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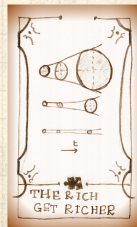
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Mechanism: Random addition and subtraction



Compare across realizations, no competition.



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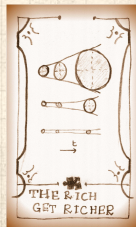
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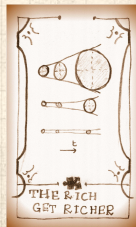
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- Widespread:** Words, Cities, the Web, Wealth, Productivity (Lotka), Popularity (Books, People, ...)



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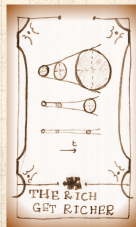
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-  **Widespread:** Words, Cities, the Web, Wealth, Productivity (Lotka), Popularity (Books, People, ...)
-  Competing mechanisms (trickiness)



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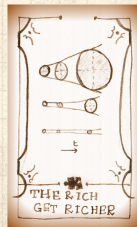
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Pre-Zipf's law observations of Zipf's law



1910s: Word frequency examined re Stenography  (or shorthand or brachygraphy or tachygraphy), Jean-Baptiste Estoup  ^[5].

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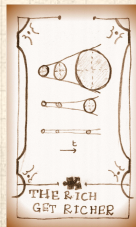
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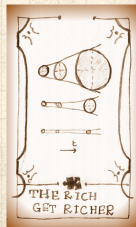
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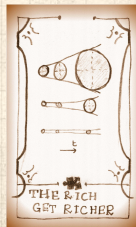
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Species per Genus (offers first theoretical mechanism)



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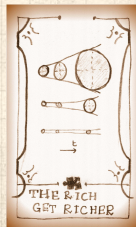
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 1926: **Lotka** ^[7]:
Scientific papers per author (Lotka's law)



Theoretical Work of Yore:



1949: Zipf's "Human Behaviour and the Principle of Least-Effort" is published. ^[12]

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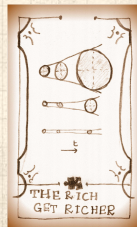
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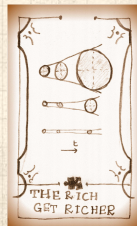
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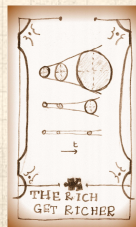
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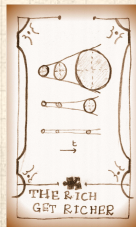
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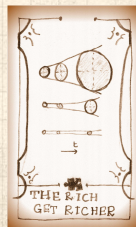
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-  1999: **Barabasi and Albert** ^[2]:
The World Wide Web, networks-at-large.





Herbert Simon  (1916–2001):



Political scientist (and much more)

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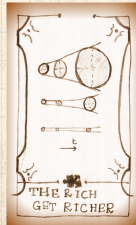
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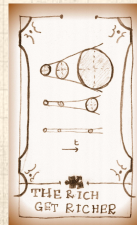
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Coined ‘bounded rationality’ and ‘satisficing’



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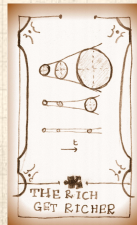
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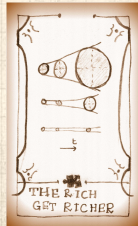
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- Nearly 1000 publications (see [Google Scholar](#) ↗)
- An early leader in Artificial Intelligence, Information Processing, Decision-Making, Problem-Solving, Attention Economics, Organization Theory, Complex Systems, And Computer Simulation Of Scientific Discovery.

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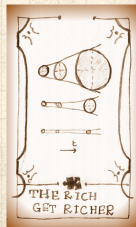
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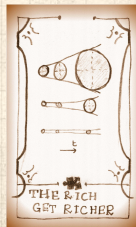
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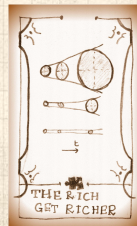
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Essential Extract of a Growth Model:

Random Competitive Replication (RCR):

1. Start with 1 Moo Deng (or element) of a particular flavor at $t = 1$

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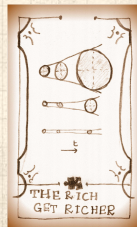
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Essential Extract of a Growth Model:

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1. Start with 1 Moo Deng (or element) of a particular flavor at $t = 1$
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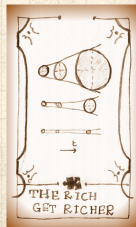
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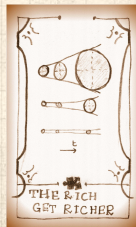
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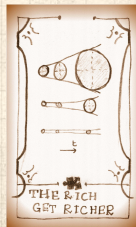
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= **Mutation/Innovation**
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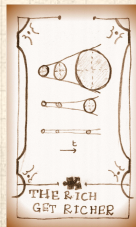
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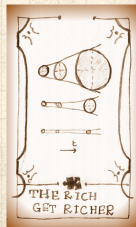
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Random Competitive Replication (RCR):

1. Start with 1 Moo Deng (or element) of a particular flavor at $t = 1$
2. At time $t = 2, 3, 4, \dots$, add a new elephant in one of two ways:
 - With probability ρ , create a new elephant with a new flavor
= Mutation/Innovation
 - With probability $1 - \rho$, randomly choose from all existing elephants, and make a copy.
= Replication/Imitation
 - Elephants of the same flavor form a group



Random Competitive Replication—Simon's rich-get-richer model: ^[10]

Example: Words appearing in a language

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Rich-Get-Richer
Mechanism

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What Came Before

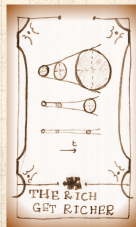
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Random Competitive Replication—Simon's rich-get-richer model: ^[10]

Example: Words appearing in a language

 Consider words as they appear sequentially.

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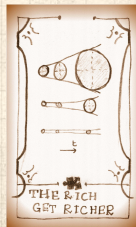
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Example: Words appearing in a language

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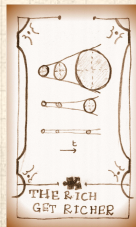
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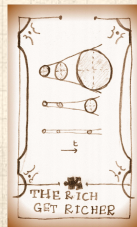
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Example: Words appearing in a language

- Consider words as they appear sequentially.
- With probability ρ , the next word has not previously appeared
- With probability $1 - \rho$, randomly choose one word from all words that have come before, and reuse this word



Random Competitive Replication—Simon's rich-get-richer model: ^[10]

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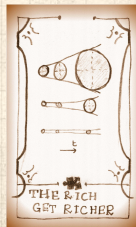
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= **Mutation/Innovation**
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Random Competitive Replication—Simon's rich-get-richer model: ^[10]

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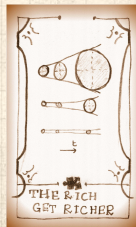
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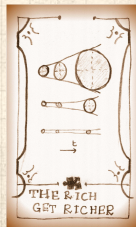
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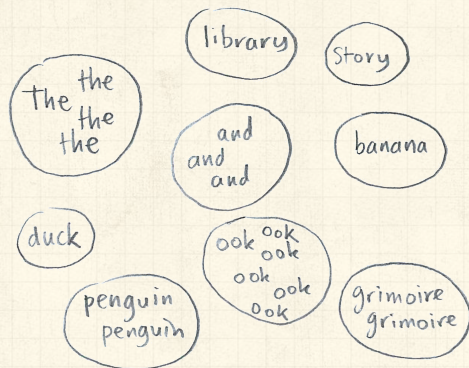
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- With probability ρ , the next word has not previously appeared
= **Mutation/Innovation**
- With probability $1 - \rho$, randomly choose one word from all words that have come before, and reuse this word
= **Replication/Imitation**

Note: This is a terrible way to write a novel.



For example:



- 21 words used
 - next word is new with prob p
 - next word is a copy with prob $1-p$
- | prob: | next word: |
|----------|------------|
| $6/21$ | ook |
| $4/21$ | the |
| $3/21$ | and |
| $2/21$ | penguin |
| $\vdots$ | |
| $1/21$ | library |

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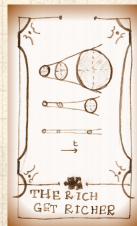
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Some observations:



Fundamental **Rich-get-Richer** story;

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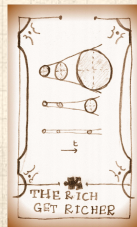
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Some observations:



Fundamental **Rich-get-Richer** story;



Competition for replication between individual elephants is random;

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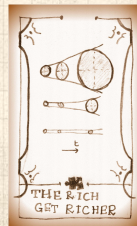
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- 🧱 Competition for replication between individual elephants is random;
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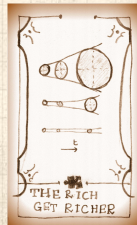
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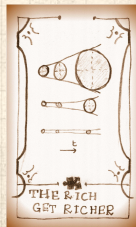
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- ❏ Competition for growth between groups of matching elephants is not random;
- ❏ Selection on groups is biased by size;
- ❏ Random selection sounds **easy**;

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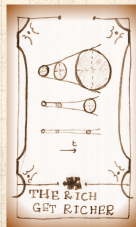
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- 🧱 Random selection sounds **easy**;
- 🧱 Possible that no great knowledge of system needed (but more later ...).

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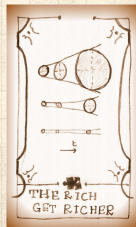
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-  Random selection sounds **easy**;
-  Possible that no great knowledge of system needed (but more later ...).

Your free set of tofu knives:

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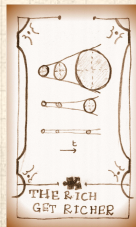
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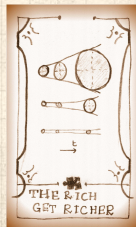


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-  Random selection sounds **easy**;
-  Possible that no great knowledge of system needed (but more later ...).

Your free set of tofu knives:

-  Related to Pólya's Urn Model , a special case of problems involving urns and colored balls .

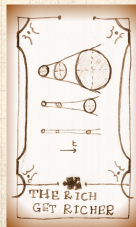


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-  Selection on groups is biased by size;
-  Random selection sounds **easy**;
-  Possible that no great knowledge of system needed (but more later ...).

Your free set of tofu knives:

-  Related to Pólya's Urn Model , a special case of problems involving urns and colored balls .
-  Sampling with super-duper replacement and sneaky sneaking in of new colors.



The long tail of religious studies?

August 5, 2010 @ 10:33 am · Filed by [Mark Liberman](#) under [Computational linguistics](#)

[« previous post](#) | [next post »](#)

Google Books isn't the only outfit that sometimes has [trouble](#) with [metadata](#). I happened to notice this morning that Oxford University Press has classified [Herbert A. Simon's "On a class of skew distribution functions"](#) (*Biometrika* 43:425-440, 1955) as "Religious Studies..Death":

BIOMETRIKA

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[Oxford Journals](#) > [Mathematics & Physical Sciences](#) > [Biometrika](#) > [Volume 42, Numb](#)

Biometrika 1955 42(3-4):425-440; doi:10.1093/biomet/42.3-4.425
© 1955 by [Biometrika Trust](#)

ON A CLASS OF SKEW DISTRIBUTION FUNCTIONS

HERBERT A. SIMON

You have reached the most complete version of this article accessible without further authentication.

More complete versions are available.

[Link to article](#)

Article topics:

- Religious Studies..Death

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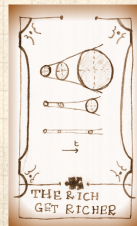
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Carl Burke said,

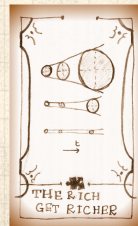
August 5, 2010 @ 12:14 pm

If I had to guess at features that suggest 'Religious Studies — Death', I'd have to go with the word 'urn' and the suffix 'xion', almost never seen except on 'crucifixion'. Granted that Biometrika is published by Oxford University Press, and 'connexion' is a perfectly good British word, the classification algorithm might be more familiar with the American form 'connection'.

[(myl) Looking a bit further into the paper, one finds things like

it is well known that the negative binomial and the log series distributions can be obtained as the stationary solutions of certain stochastic processes. For example, J.H. Darwin (1953) derives these from birth and death processes, with appropriate assumptions as to the birth- and death-rates and the initial conditions.

]



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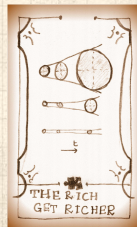
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Some observations:



Steady growth of system: +1 elephant per unit time.



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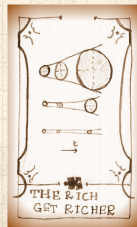
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Some observations:

🧱 Steady growth of system: +1 elephant per unit time.

🧱 Steady growth of distinct flavors at **rate ρ**



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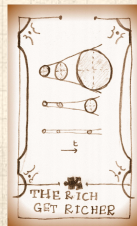
References

Some observations:

🧱 Steady growth of system: +1 elephant per unit time.

🧱 Steady growth of distinct flavors at **rate ρ**

🧱 We can incorporate



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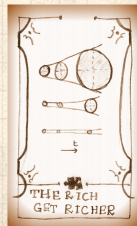
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 We can incorporate

1. Elephant elimination



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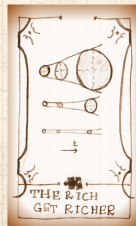
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 Steady growth of distinct flavors at **rate ρ**

 We can incorporate

1. Elephant elimination
2. Elephants moving between groups



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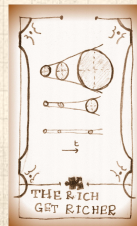
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 Steady growth of system: +1 elephant per unit time.

 Steady growth of distinct flavors at **rate ρ**

 We can incorporate

1. Elephant elimination
2. Elephants moving between groups
3. Variable innovation rate ρ



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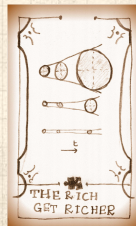
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 Steady growth of distinct flavors at **rate ρ**

 We can incorporate

1. Elephant elimination
2. Elephants moving between groups
3. Variable innovation rate ρ
4. Different selection based on group size



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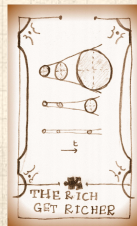
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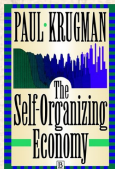
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 Steady growth of distinct flavors at **rate ρ**

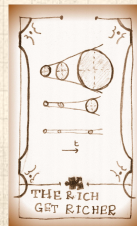
 We can incorporate

1. Elephant elimination
2. Elephants moving between groups
3. Variable innovation rate ρ
4. Different selection based on group size
(But mechanism for selection is not as simple...)





“The Self-Organizing Economy” [a](#) [↗](#)
by Paul Krugman (1996). ^[6]

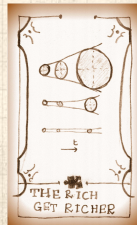




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Ch. 3: An Urban Mystery, p. 46

“...Simon showed—in a completely impenetrable exposition!—that the exponent of the power law distribution should be ...”^{1, 2}



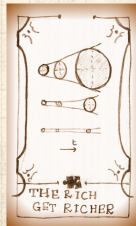


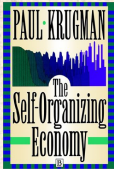
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Ch. 3: An Urban Mystery, p. 46

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¹Krugman’s book was handed to the Deliverator by a certain [Álvaro Cartea](#) [↗](#)
many years ago at the Santa Fe Institute Summer School.

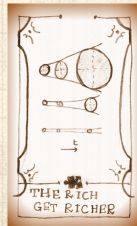




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²Let’s use π for probability because π ’s not special, right guys?

From an archaeological email dig:

% cat ~/Mail/2018-04-13pine-uvn/past/archive-
2009-09-25/PaulKrugman

● ● ● Duck-Billed-Platypus-2024.local:/Users/dodds/pocverse/lectures — more ~...

id AA06867; Thu, 19 Feb 98 08:53:53 EST
Received: from KRUGMAN.MIT.EDU by MIT.MIT.EDU (5.61/4.7) id AA15443; Thu, 19 Feb 98 08:53:32 EST
Message-Id: <2.2.32.19980219135345.00989f60@po10.mit.edu>
X-Sender: krugman@po10.mit.edu
X-Mailer: Windows Eudora Pro Version 2.2 (32)
Mime-Version: 1.0
Content-Type: text/plain; charset="us-ascii"
Date: Thu, 19 Feb 1998 08:53:45 -0500
To: Peter Sheridan Dodds <dodds@math.mit.edu>
From: "Paul R. Krugman" <krugman@MIT.EDU>
Subject: Re: a reference please (very quick!)

Status: RO
X-Status:
X-Keywords:

At 06:47 PM 2/18/98 -0500, you wrote:
>prof krugman,
>
>i was hoping that you might have a second to pass
>on the reference for Herbert Simon's paper
>'on a class of skew distribution functions'...
>
It's in Biometrika, of all places. But also in Simon's collected papers (I think titled Models of Mind); and the basics are repeated in a book by him and Ijiri, "skew distributions and the sizes of firms" (I think)

For all this, and a MUCH simpler derivation of Simon's rule, check out my own book The self-organizing economy

Paul Krugman
Department of Economics, MIT
50 Memorial Drive
Cambridge, MA 02139
617-253-1551/fax 617-253-4096
email: krugman@mit.edu
home page: <http://web.mit.edu/krugman/www/>

(END)

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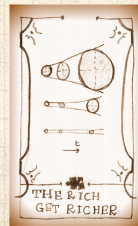
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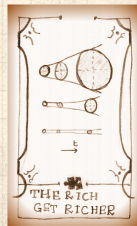
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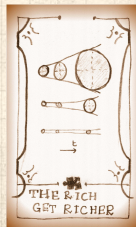
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Definitions:



k_i = size of a group i



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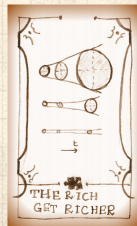
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Definitions:

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 $N_{k,t}$ = # groups containing k elephants at time t .



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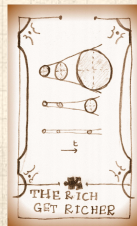
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Definitions:

 k_i = size of a group i

 $N_{k,t}$ = # groups containing k elephants at time t .

Basic question: How does $N_{k,t}$ evolve with time?



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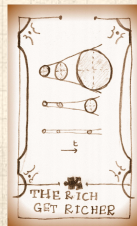
Definitions:

 k_i = size of a group i

 $N_{k,t}$ = # groups containing k elephants at time t .

Basic question: How does $N_{k,t}$ evolve with time?

First: $\sum_k k N_{k,t} = t$ = number of elephants at time t



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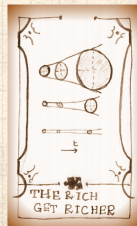
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$P_k(t)$ = Probability of choosing an elephant that belongs to a group of size k :



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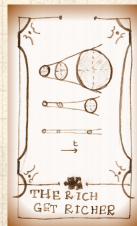
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$P_k(t)$ = Probability of choosing an elephant that belongs to a group of size k :

 $N_{k,t}$ size k groups



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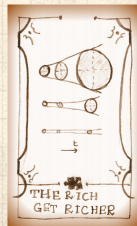
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$P_k(t)$ = Probability of choosing an elephant that belongs to a group of size k :

 $N_{k,t}$ size k groups

 $\Rightarrow kN_{k,t}$ elephants in size k groups



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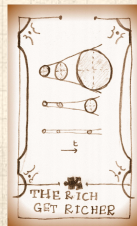
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$P_k(t)$ = Probability of choosing an elephant that belongs to a group of size k :

 $N_{k,t}$ size k groups

 $\Rightarrow kN_{k,t}$ elephants in size k groups

 t elephants overall



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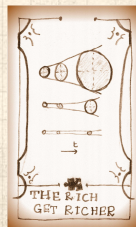
$P_k(t)$ = Probability of choosing an elephant that belongs to a group of size k :

 $N_{k,t}$ size k groups

 $\Rightarrow kN_{k,t}$ elephants in size k groups

 t elephants overall

$$P_k(t) = \frac{kN_{k,t}}{t}.$$



Random Competitive Replication:

$N_{k,t}$, the number of groups with k elephants, changes at time t if

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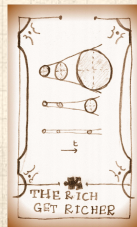
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Random Competitive Replication:

$N_{k,t}$, the number of groups with k elephants, changes at time t if

1. An elephant belonging to a group with k elephants is replicated:

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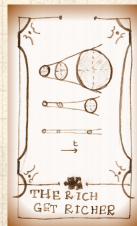
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Random Competitive Replication:

$N_{k,t}$, the number of groups with k elephants, changes at time t if

1. An elephant belonging to a group with k elephants is replicated:
2. An elephant belonging to a group with $k - 1$ elephants is replicated:

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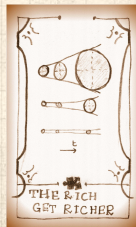
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Random Competitive Replication:

$N_{k,t}$, the number of groups with k elephants, changes at time t if

1. An elephant belonging to a group with k elephants is replicated:

$$N_{k,t+1} = N_{k,t} - 1$$

2. An elephant belonging to a group with $k - 1$ elephants is replicated:

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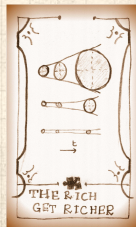
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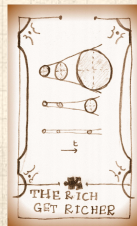
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$$N_{k,t+1} = N_{k,t} - 1$$

Happens with probability $(1 - \rho)kN_{k,t}/t$

2. An elephant belonging to a group with $k - 1$ elephants is replicated:



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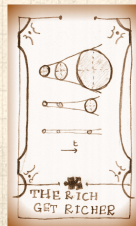
1. An elephant belonging to a group with k elephants is replicated:

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Happens with probability $(1 - \rho)kN_{k,t}/t$

2. An elephant belonging to a group with $k - 1$ elephants is replicated:

$$N_{k,t+1} = N_{k,t} + 1$$



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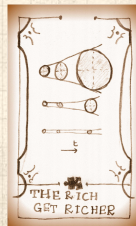
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2. An elephant belonging to a group with $k - 1$ elephants is replicated:

$$N_{k,t+1} = N_{k,t} + 1$$

Happens with probability $(1 - \rho)(k - 1)N_{k-1,t}/t$



Random Competitive Replication:

Special case for $N_{1,t}$:

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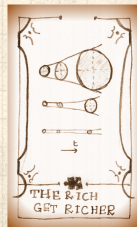
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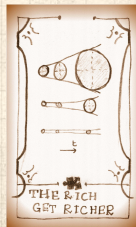
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Special case for $N_{1,t}$:

1. The new elephant is a new flavor:



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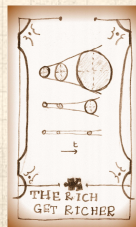
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Special case for $N_{1,t}$:

1. The new elephant is a new flavor:
2. A unique elephant is replicated:



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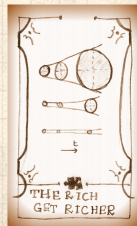
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Special case for $N_{1,t}$:

1. The new elephant is a new flavor:

$$N_{1,t+1} = N_{1,t} + 1$$

2. A unique elephant is replicated:



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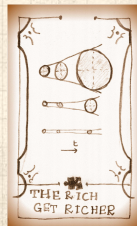
Special case for $N_{1,t}$:

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$$N_{1,t+1} = N_{1,t} + 1$$

Happens with probability ρ

2. A unique elephant is replicated:



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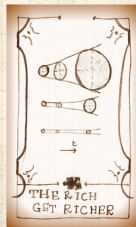
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Happens with probability ρ

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$$N_{1,t+1} = N_{1,t} - 1$$



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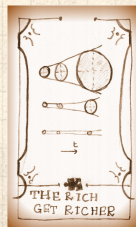
$$N_{1,t+1} = N_{1,t} + 1$$

Happens with probability ρ

2. A unique elephant is replicated:

$$N_{1,t+1} = N_{1,t} - 1$$

Happens with probability $(1 - \rho)N_{1,t}/t$



Random Competitive Replication:

Putting everything together:

For $k > 1$:

$$\langle N_{k,t+1} - N_{k,t} \rangle = (1-\rho) \left((+1)(k-1) \frac{N_{k-1,t}}{t} + (-1)k \frac{N_{k,t}}{t} \right)$$

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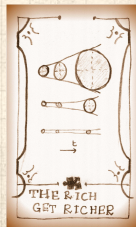
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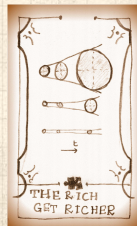
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For $k > 1$:

$$\langle N_{k,t+1} - N_{k,t} \rangle = (1-\rho) \left((+1)(k-1) \frac{N_{k-1,t}}{t} + (-1)k \frac{N_{k,t}}{t} \right)$$

For $k = 1$:

$$\langle N_{1,t+1} - N_{1,t} \rangle = (+1)\rho + (-1)(1-\rho)1 \cdot \frac{N_{1,t}}{t}$$



Random Competitive Replication:

Assume distribution stabilizes: $N_{k,t} = n_k t$
(Reasonable for t large)

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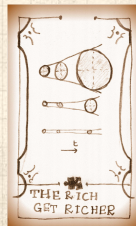
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Drop expectations

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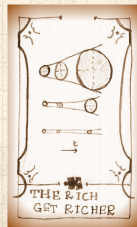
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Numbers of elephants now fractional

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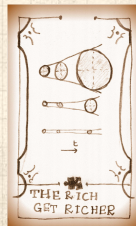
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Drop expectations



Numbers of elephants now fractional



Okay over large time scales

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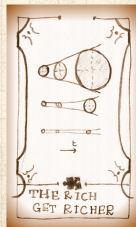
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Random Competitive Replication:

Assume distribution stabilizes: $N_{k,t} = n_k t$
(Reasonable for t large)



Drop expectations



Numbers of elephants now fractional



Okay over large time scales



For later: the fraction of groups that have size k is n_k/ρ since

$$\frac{N_{k,t}}{\rho t} = \frac{n_k t}{\rho t} = \frac{n_k}{\rho}.$$

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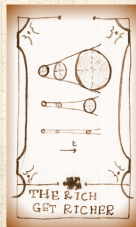
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Random Competitive Replication:

Stochastic difference equation:

$$\langle N_{k,t+1} - N_{k,t} \rangle = (1 - \rho) \left((k-1) \frac{N_{k-1,t}}{t} - k \frac{N_{k,t}}{t} \right)$$

becomes

$$n_k(t+1) - n_k t = (1 - \rho) \left((k-1) \frac{n_{k-1} t}{t} - k \frac{n_k t}{t} \right)$$

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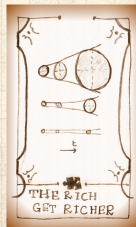
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becomes

$$n_k(t+1) - n_k t = (1 - \rho) \left((k-1) \frac{n_{k-1} t}{t} - k \frac{n_k t}{t} \right)$$

$$n_k(\cancel{t} + 1 - \cancel{t}) = (1 - \rho) \left((k-1) \frac{n_{k-1} \cancel{t}}{\cancel{t}} - k \frac{n_k \cancel{t}}{\cancel{t}} \right)$$

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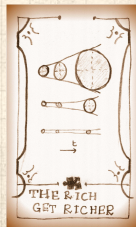
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$$n_k(\cancel{t} + 1 - \cancel{t}) = (1 - \rho) \left((k-1) \frac{n_{k-1} \cancel{t}}{\cancel{t}} - k \frac{n_k \cancel{t}}{\cancel{t}} \right)$$

$$\Rightarrow n_k = (1 - \rho) ((k-1)n_{k-1} - kn_k)$$

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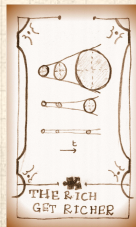
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Random Competitive Replication:

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becomes

$$n_k(t+1) - n_k t = (1 - \rho) \left((k-1) \frac{n_{k-1} t}{t} - k \frac{n_k t}{t} \right)$$

$$n_k(\cancel{t} + 1 - \cancel{t}) = (1 - \rho) \left((k-1) \frac{n_{k-1} \cancel{t}}{\cancel{t}} - k \frac{n_k \cancel{t}}{\cancel{t}} \right)$$

$$\Rightarrow n_k = (1 - \rho) ((k-1)n_{k-1} - kn_k)$$

$$\Rightarrow n_k (1 + (1 - \rho)k) = (1 - \rho)(k-1)n_{k-1}$$

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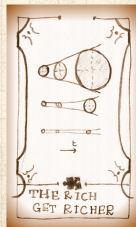
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Random Competitive Replication:

We have a simple recursion:

$$\frac{n_k}{n_{k-1}} = \frac{(k-1)(1-\rho)}{1 + (1-\rho)k}$$

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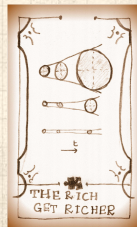
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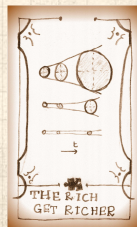
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-  Can be solved exactly.

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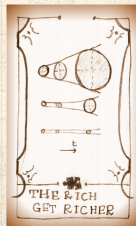
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Insert assignment question 

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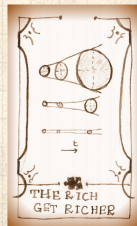
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 For just the tail: Expand as a series of powers of $1/k$

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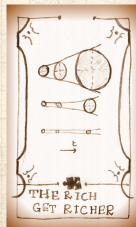
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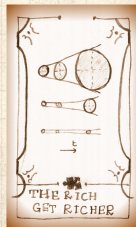
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Insert assignment question 

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Insert assignment question 

We (okay, you) find

$$n_k \propto k^{-\frac{(2-\rho)}{(1-\rho)}} = k^{-\gamma}$$

$$\gamma = \frac{(2-\rho)}{(1-\rho)} = 1 + \frac{1}{(1-\rho)}$$

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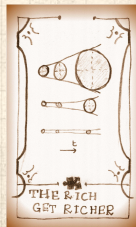
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Micro-to-Macro story with ρ and γ measurable.

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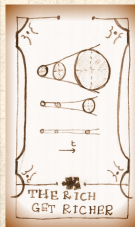
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$$\gamma = \frac{(2 - \rho)}{(1 - \rho)} = 1 + \frac{1}{(1 - \rho)}$$



Observe $2 < \gamma < \infty$ for $0 < \rho < 1$.

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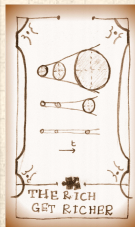
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For $\rho \simeq 0$ (low innovation rate):

$$\gamma \simeq 2$$

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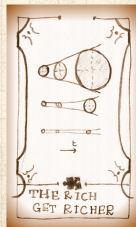
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‘Wild’ power-law size distribution of group sizes, bordering on ‘infinite’ mean.

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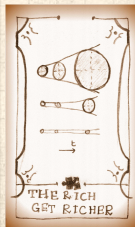
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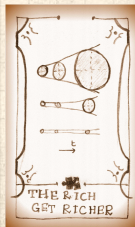
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All elephants have different flavors.

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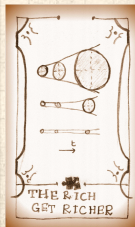
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Upshot: Tunable mechanism producing a family of universality classes.

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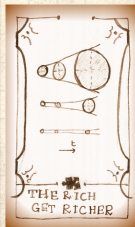
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Recall size-ranking law: $s_r \sim r^{-\alpha}$
(s_r = size of the r th largest group of elephants)

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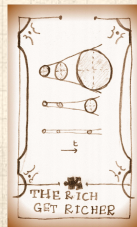
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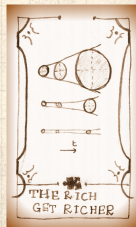
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We found $\alpha = 1/(\gamma - 1)$ so:

$$\alpha = \frac{1}{\gamma - 1} = \frac{1}{\cancel{\gamma} + \frac{1}{(1-\rho)} - \cancel{\gamma}} = 1 - \rho.$$





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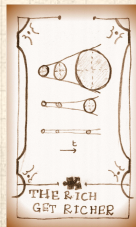


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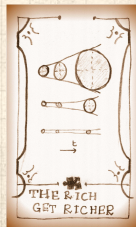
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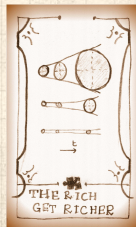
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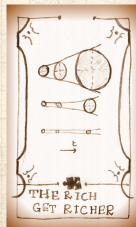
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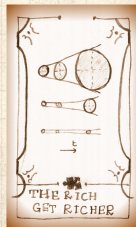
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 Must look at the details to see if mechanism makes sense...
more later.



What about small k ?:

We had one other equation:



$$\langle N_{1,t+1} - N_{1,t} \rangle = \rho - (1 - \rho)1 \cdot \frac{N_{1,t}}{t}$$

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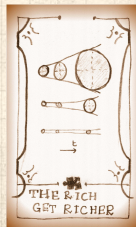
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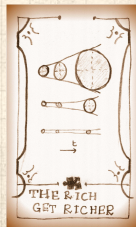
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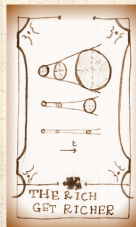
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$$n_1 = \rho - (1 - \rho)n_1$$



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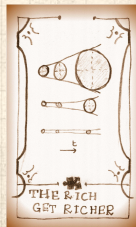


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Rearrange:

$$n_1 + (1 - \rho)n_1 = \rho$$



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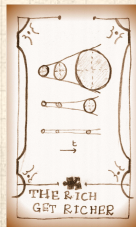


Rearrange:

$$n_1 + (1 - \rho)n_1 = \rho$$



$$n_1 = \frac{\rho}{2 - \rho}$$



So...
$$N_{1,t} = n_1 t = \frac{\rho t}{2 - \rho}$$

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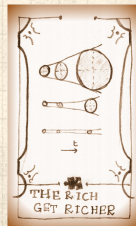
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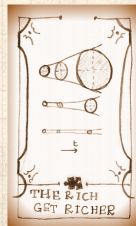
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Recall number of distinct elephants = ρt .



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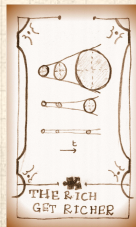
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Fraction of distinct elephants that are unique (belong to groups of size 1):

$$\frac{1}{\rho t} N_{1,t} = \frac{1}{\cancel{\rho t}} \frac{\cancel{\rho t}}{2 - \rho} = \frac{1}{2 - \rho}$$

(also = fraction of groups of size 1)



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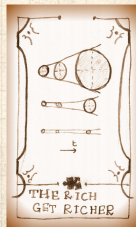
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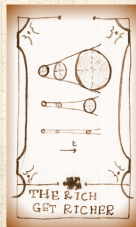
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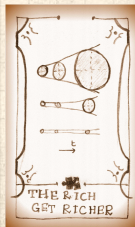
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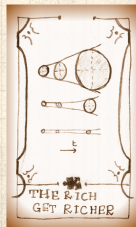
Roughly observed for real distributions



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Can show fraction of groups with two elephants $\sim 1/6$



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Recall number of distinct elephants = ρt .



Fraction of distinct elephants that are unique (belong to groups of size 1):

$$\frac{1}{\rho t} N_{1,t} = \frac{1}{\cancel{\rho t}} \frac{\cancel{\rho t}}{2 - \rho} = \frac{1}{2 - \rho}$$

(also = fraction of groups of size 1)



For ρ small, fraction of unique elephants $\sim 1/2$



Roughly observed for real distributions



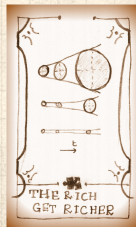
ρ increases, fraction increases



Can show fraction of groups with two elephants $\sim 1/6$



Model works well for large and small k



So...
$$N_{1,t} = n_1 t = \frac{\rho t}{2 - \rho}$$



Recall number of distinct elephants = ρt .



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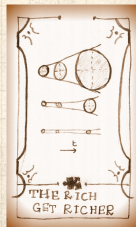
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Can show fraction of groups with two elephants $\sim 1/6$



Model works well for large and small k #awesome



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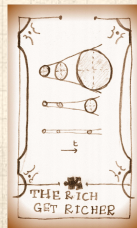
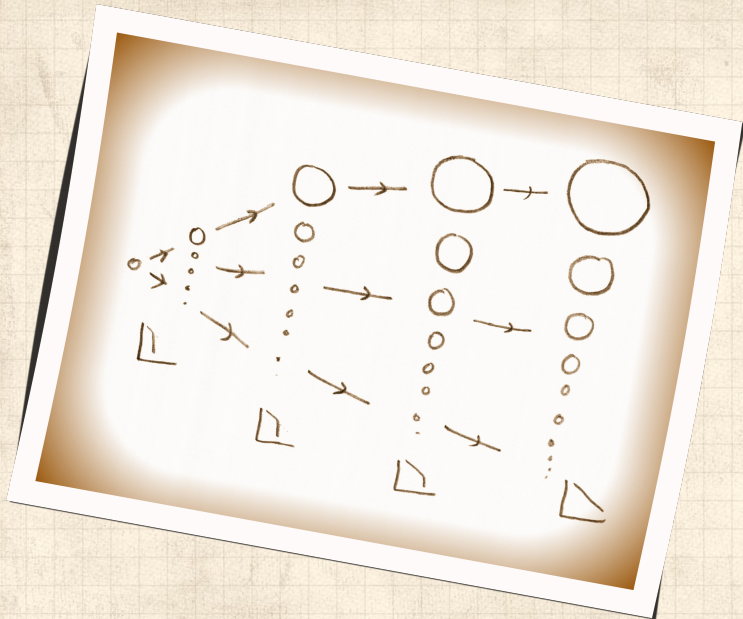
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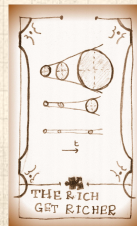
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From Simon ^[10]:

Estimate $\rho_{\text{est}} = \# \text{ unique words} / \# \text{ all words}$

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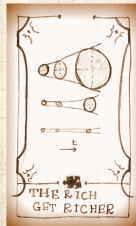
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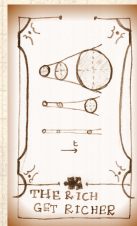
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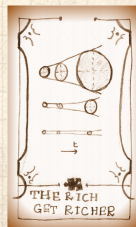
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For Joyce's **Ulysses**: $\rho_{\text{est}} \simeq 0.115$

N_1 (real)	N_1 (est)	N_2 (real)	N_2 (est)
16,432	15,850	4,776	4,870



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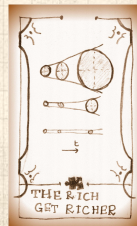
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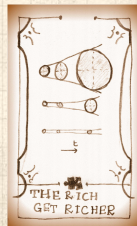
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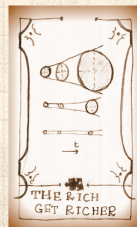
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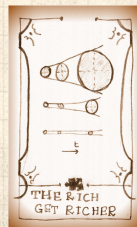
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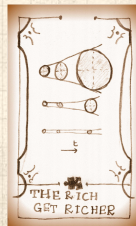
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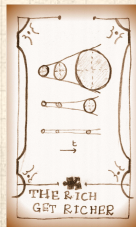
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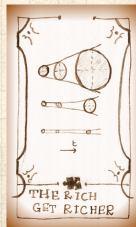
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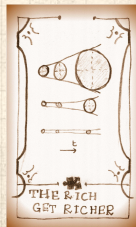
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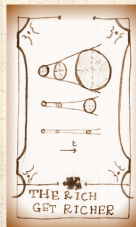
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Derek de Solla Price:



First to study network evolution with these kinds of models.

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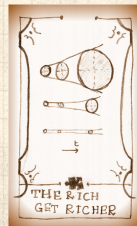
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- Citation network of scientific papers

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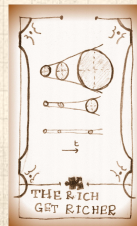
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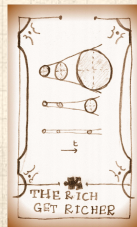
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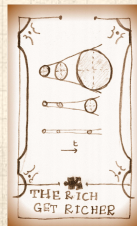
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Derek de Solla Price:

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-  Idea: papers receive new citations with probability proportional to their existing # of citations



Evolution of catch phrases:

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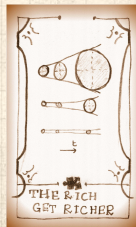
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-  Directed network



Evolution of catch phrases:

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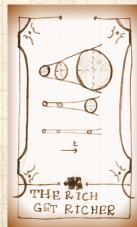
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Derek de Solla Price:

-  First to study network evolution with these kinds of models.
-  Citation network of scientific papers
-  Price's term: **Cumulative Advantage**
-  Idea: papers receive new citations with probability proportional to their existing # of citations
-  Directed network
-  Two (surmountable) problems:
 1. New papers have no citations
 2. Selection mechanism is more complicated



Evolution of catch phrases:

Robert K. Merton: the Matthew Effect 



Studied careers of scientists and found credit flowed disproportionately to the already famous

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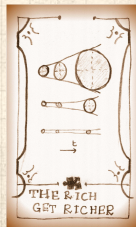
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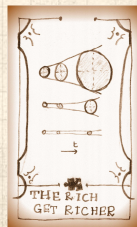
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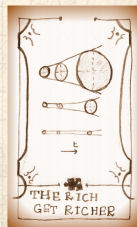
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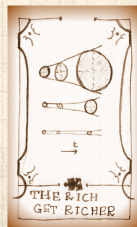
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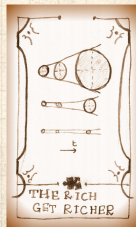
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And cast the worthless servant into the outer darkness; there men will weep and gnash their teeth.”



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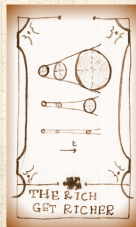
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(Hath = suggested unit of purchasing power.)



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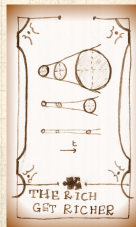
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(**Hath** = suggested unit of purchasing power.)



Matilda effect:  women's scientific achievements are often overlooked



Evolution of catch phrases:

Merton was a catchphrase machine:

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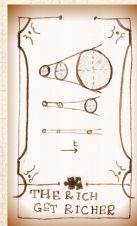
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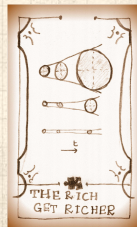
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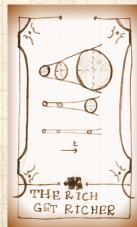
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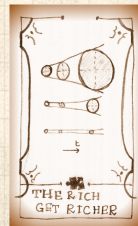
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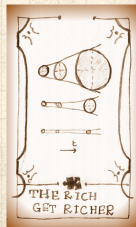
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5. Obliteration by incorporation ↗ (includes above examples from Merton himself)

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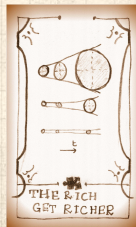
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4. Focused interview → focus group
5. Obliteration by incorporation ↗ (includes above examples from Merton himself)

And just to be clear...

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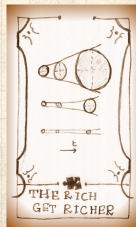
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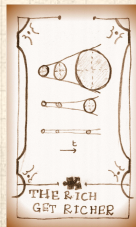
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Merton was a catchphrase machine:

1. Self-fulfilling prophecy
2. Role model
3. Unintended (or unanticipated) consequences
4. Focused interview → focus group
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And just to be clear...

Merton's son, Robert C. Merton, won the Nobel Prize for Economics in 1997.



Evolution of catch phrases:



Barabasi and Albert^[2]—thinking about the Web

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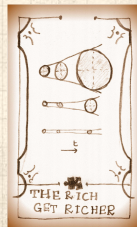
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Independent reinvention of a version of Simon and Price's theory for networks

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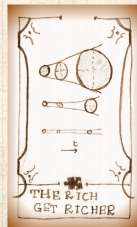
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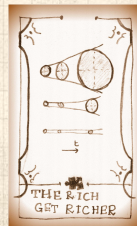
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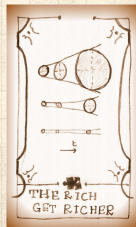
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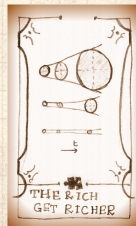
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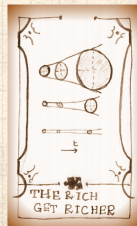
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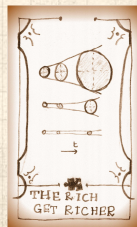
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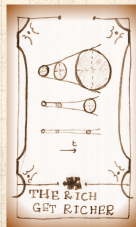
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- Still have selection problem based on size (non-random)
- Solution: Randomly connect to a node (easy) ...
- ...and then randomly connect to the node's friends (also easy)
- “Scale-free networks” = food on the table for physicists



More mattering:

Rich-get-richness in social contagion:



We love to rank everyone, everything: Top n lists.

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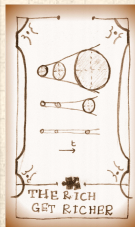
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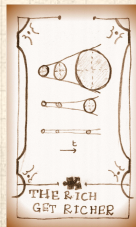
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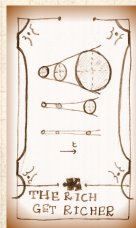
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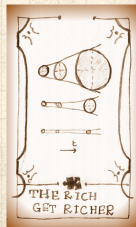
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- ✧ Black boxes are gameable but takes money and commensurate skill.

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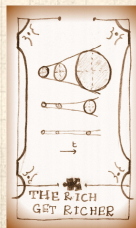
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- ✉ Black boxes are gameable but takes money and commensurate skill.
- ✉ Black box algorithms can make things spread rampantly.¹

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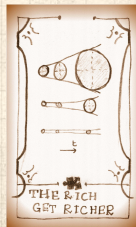
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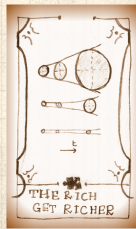
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¹“With great power comes great responsibility.” –S. Man.

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- ✉ Black box algorithms can make things spread rampantly.¹
- ✉ No “regramming” is a positive feature of Instagram (also: Pratchett the Cat ↗)

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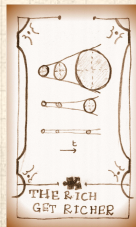
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-  Black-box ranking algorithms make ranking opaque.
-  Black boxes are gameable but takes money and commensurate skill.
-  Black box algorithms can make things spread rampantly.¹
-  No “regramming” is a positive feature of Instagram (also: Pratchett the Cat )
-  What if a healthier Facebook is just ... Instagram? 
(hahahhaaha)

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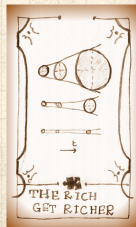
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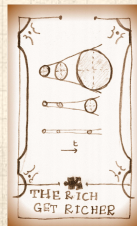
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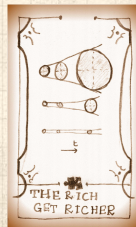
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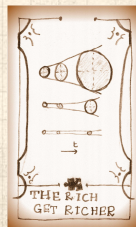
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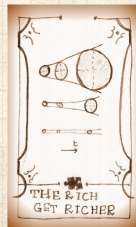
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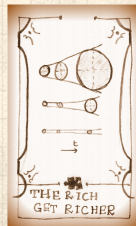
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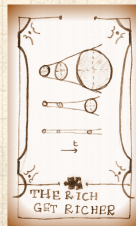
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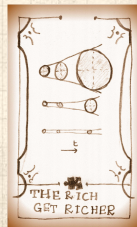
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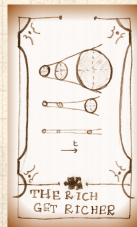
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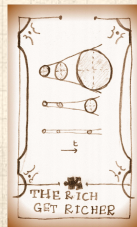
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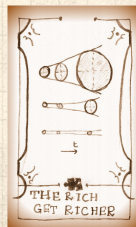
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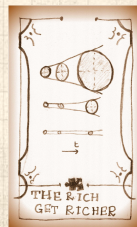
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To be continued ...

Burn it all down.





“Simon’s fundamental rich-get-richer model entails a dominant first-mover advantage” ↗

Dodds et al.,

Physical Review E, **95**, 052301, 2017. [4]

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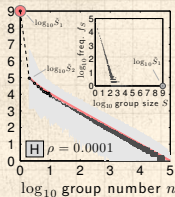
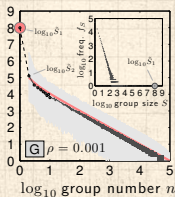
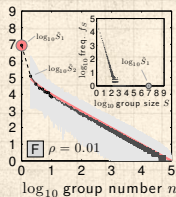
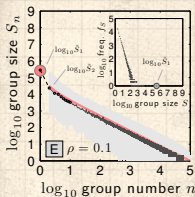
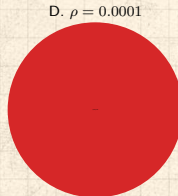
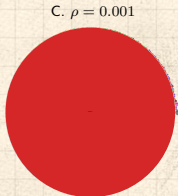
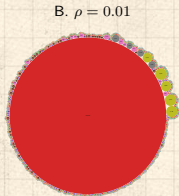
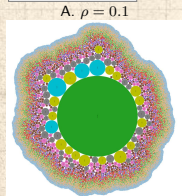
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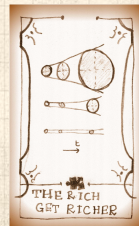
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See Fletcher Hazlehurst’s visualization at paper’s [online](#)

[app-endices](#) ↗



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Mechanism

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What Came Before

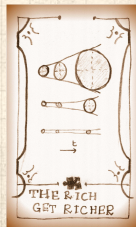
Simon's Model

Analysis

Words

Catchphrases

References



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Rich-Get-Richer
Mechanism

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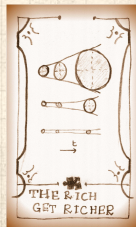
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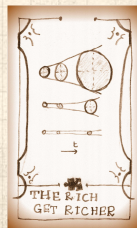
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