Modeling Network Diffusion with NetLogo

David Darmon

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Outline

- Whence and Wherefore NetLogo?
- NetLogo Abstractions
- Models of Diffusion on Networks
- Models of Network Structure

Whence and Wherefore NetLogo?

Whence and Wherefore NetLogo?

- NetLogo is a portmanteau of “network” and “Logo”.

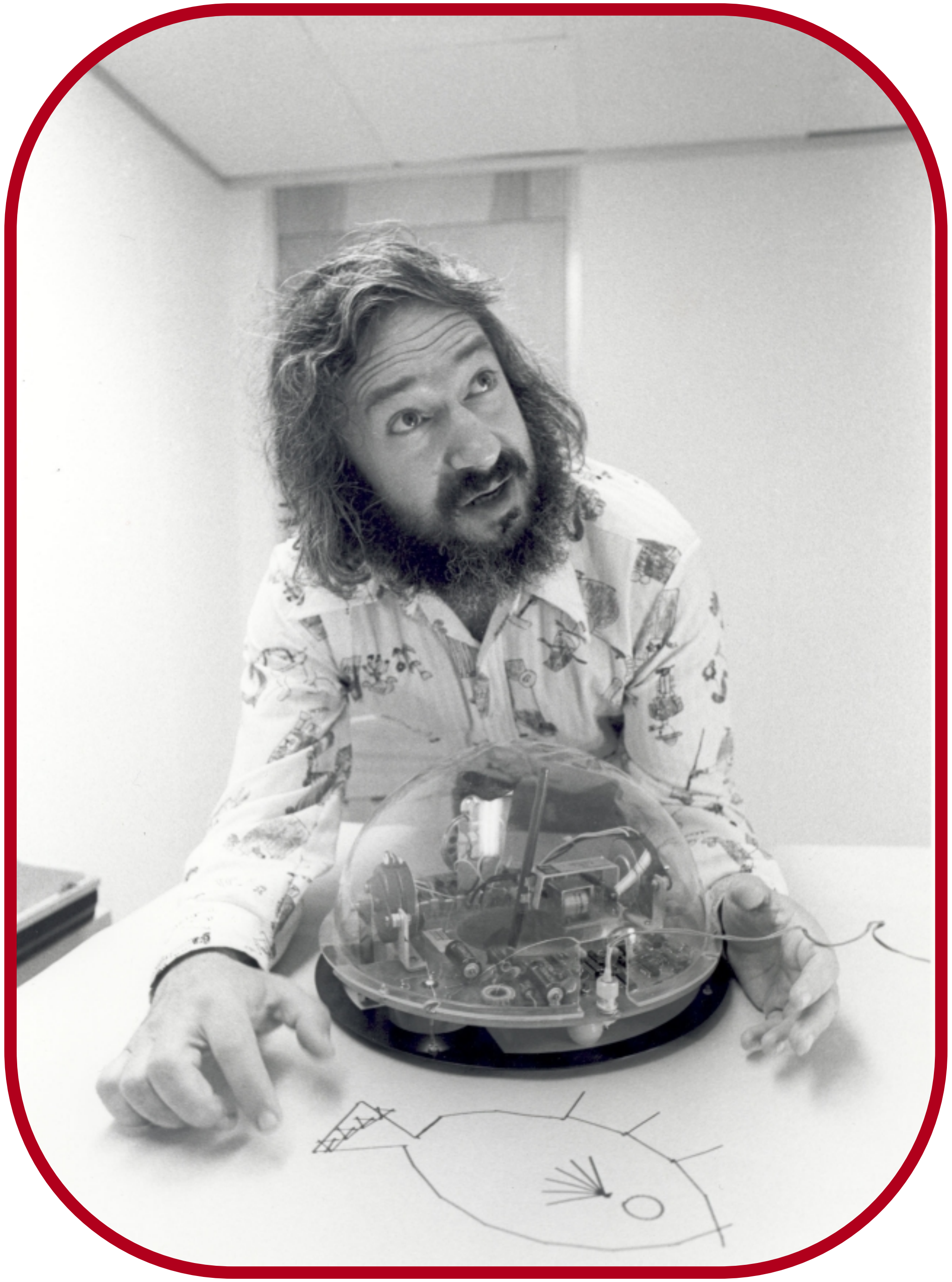
- “Network” for obvious reasons:
  - NetLogo facilitates the development of agent-based models of spatially extended systems, like networks.

- “Logo” because NetLogo is a dialect of Logo.

Whence and Wherefore NetLogo?

- Logo is a functional programming language that was first developed in 1967 by Wally Feurzeig, Seymour Papert, and Cynthia Solomon.

- Logo is based on another functional programming language, LISP.



from http://cyberneticzoo.com/

Logo

- One of the hallmarks of Logo was its ‘turtle graphics,’ where a programmer could direct the turtle to move, turn, etc.

- Papert said the turtle was an “object-for-thinking-with.”

- In much the same way, NetLogo is a programming language for thinking with (agent-based models).

NetLogo Demo

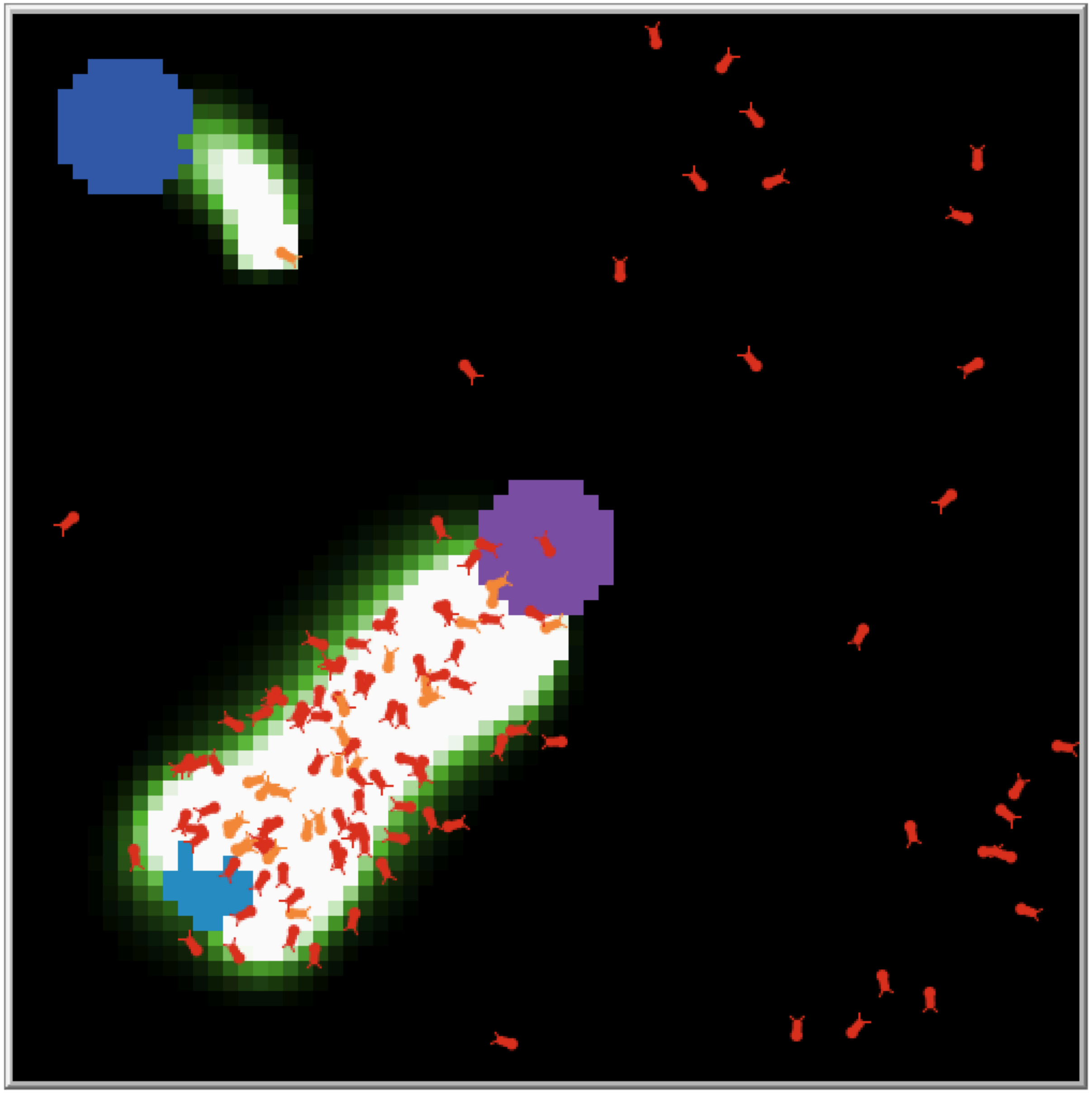
The Lingo of NetLogo

The Lingo of NetLogo

- NetLogo has four main components:
  - Turtles
  - Links
  - Patches
  - The Observer

- In the philosophy of NetLogo, all of these are agents.

The Lingo of NetLogo

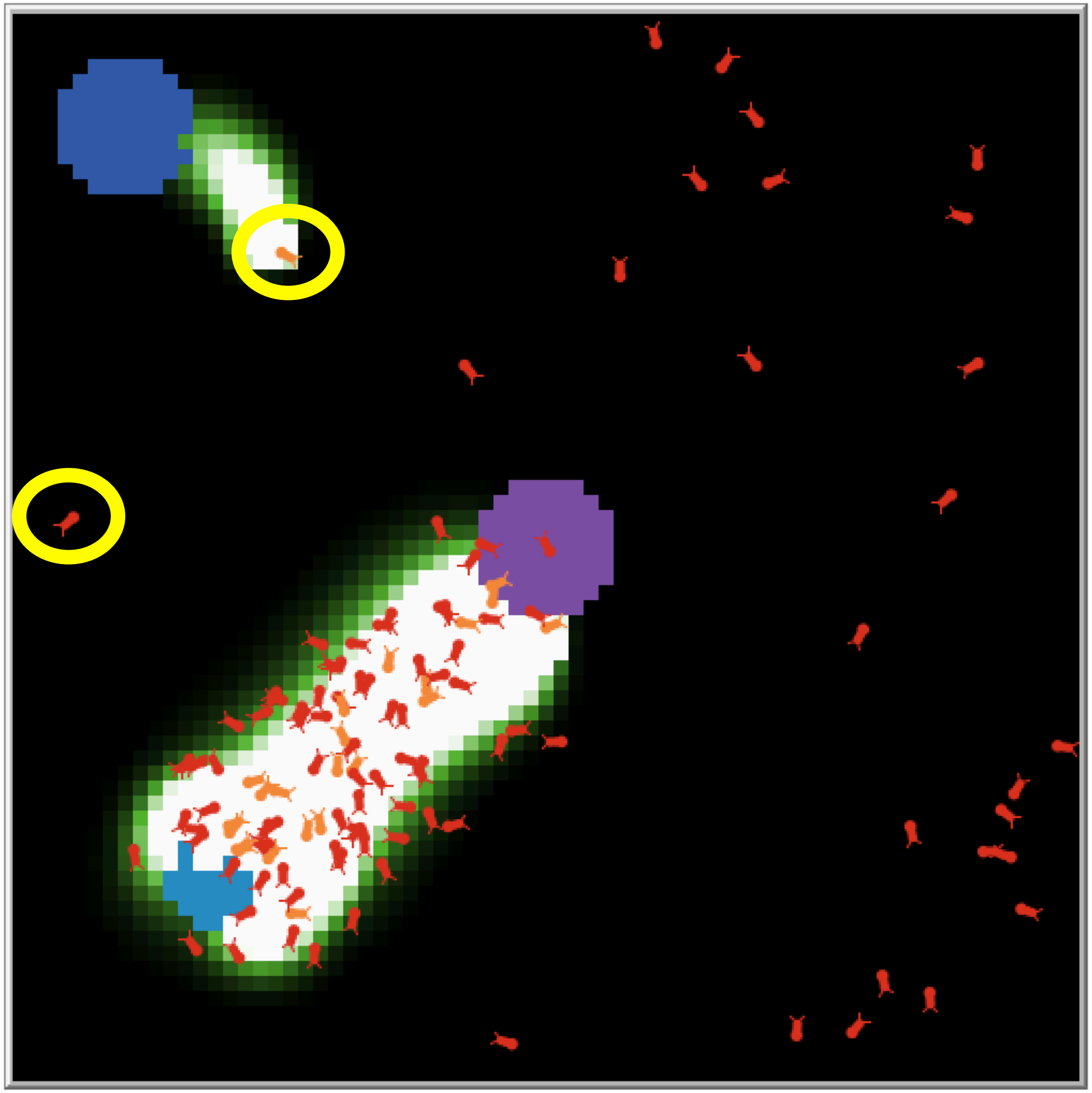


The Lingo of NetLogo

ants

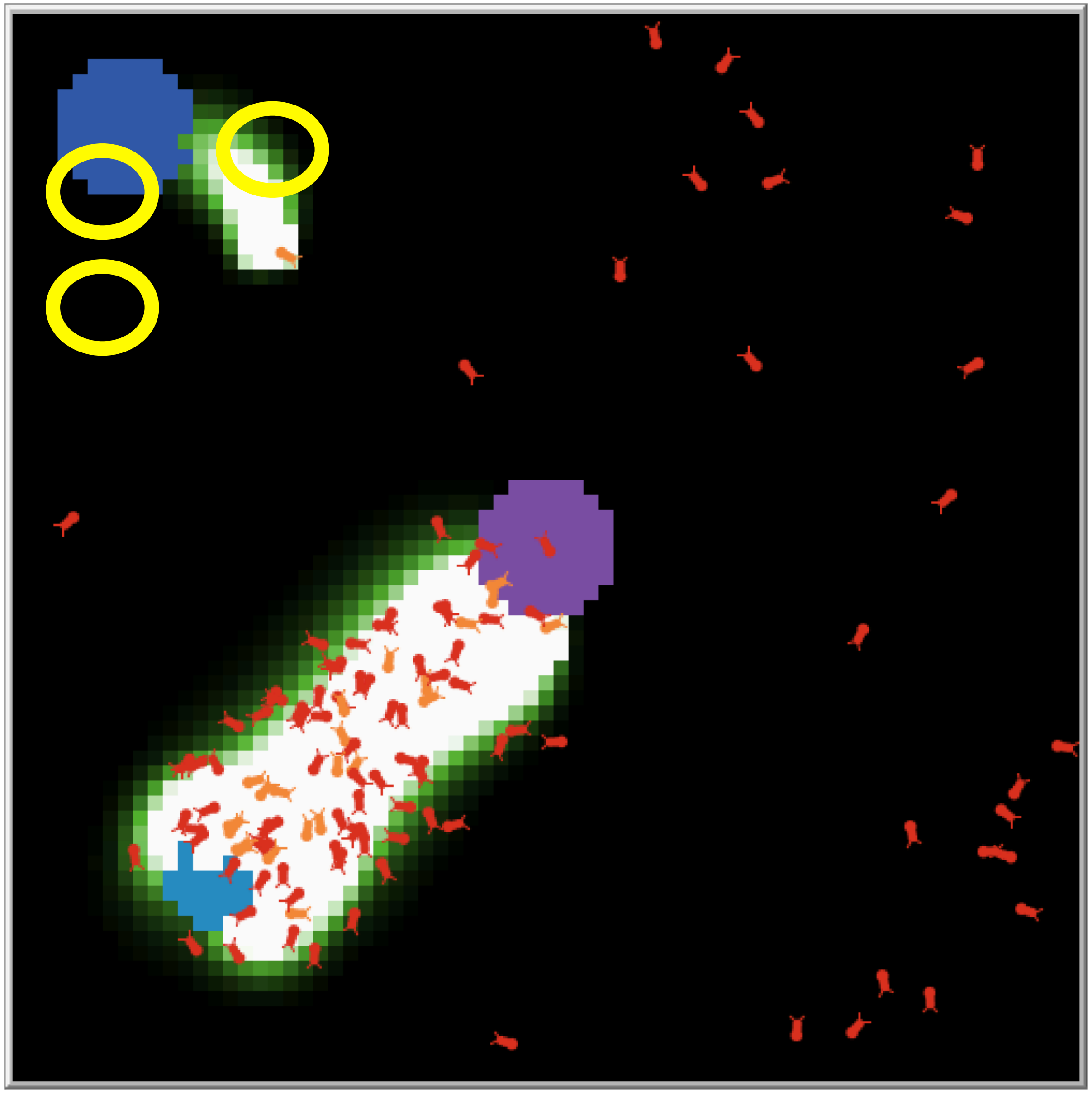
=

turtles



The Lingo of NetLogo

food
nonfood
scent trail
=
patches



Models of Diffusion on Networks

Model 1

Bass

Model 1 — Bass

- From Frank Bass's 1969 paper

  A New Product Growth [sic] *for Model Consumer Durables*

  "I suppose that I was so excited about having the paper accepted for publication that I failed to carefully proofread the galley proofs."

- A model for the adoption of new classes / types of products.

Model 1 — Bass

- The model assumes consumers adopt a new product class for one of two reasons:
  - advertising
  - word-of-mouth

- The advertising effect is *exogenous* to the consumer market.

- The word-of-mouth effect is *endogenous* to the market.

Model 1 — Bass

- Bass's original model assumed 'well-mixing' of the population, and thus ignored spatial and social effects by modeling the proportion of adopted individuals through a differential equation.

- Let $F(t)$ denote the proportion of consumers who have adopted by time t.

- Then the change in $F(t)$ is given by

$$\frac{dF(t)}{dt} = (p + qF(t))(1 - F(t))$$

Model 1 — Bass

$$\frac{dF(t)}{dt} = (p + qF(t))(1 - F(t))$$

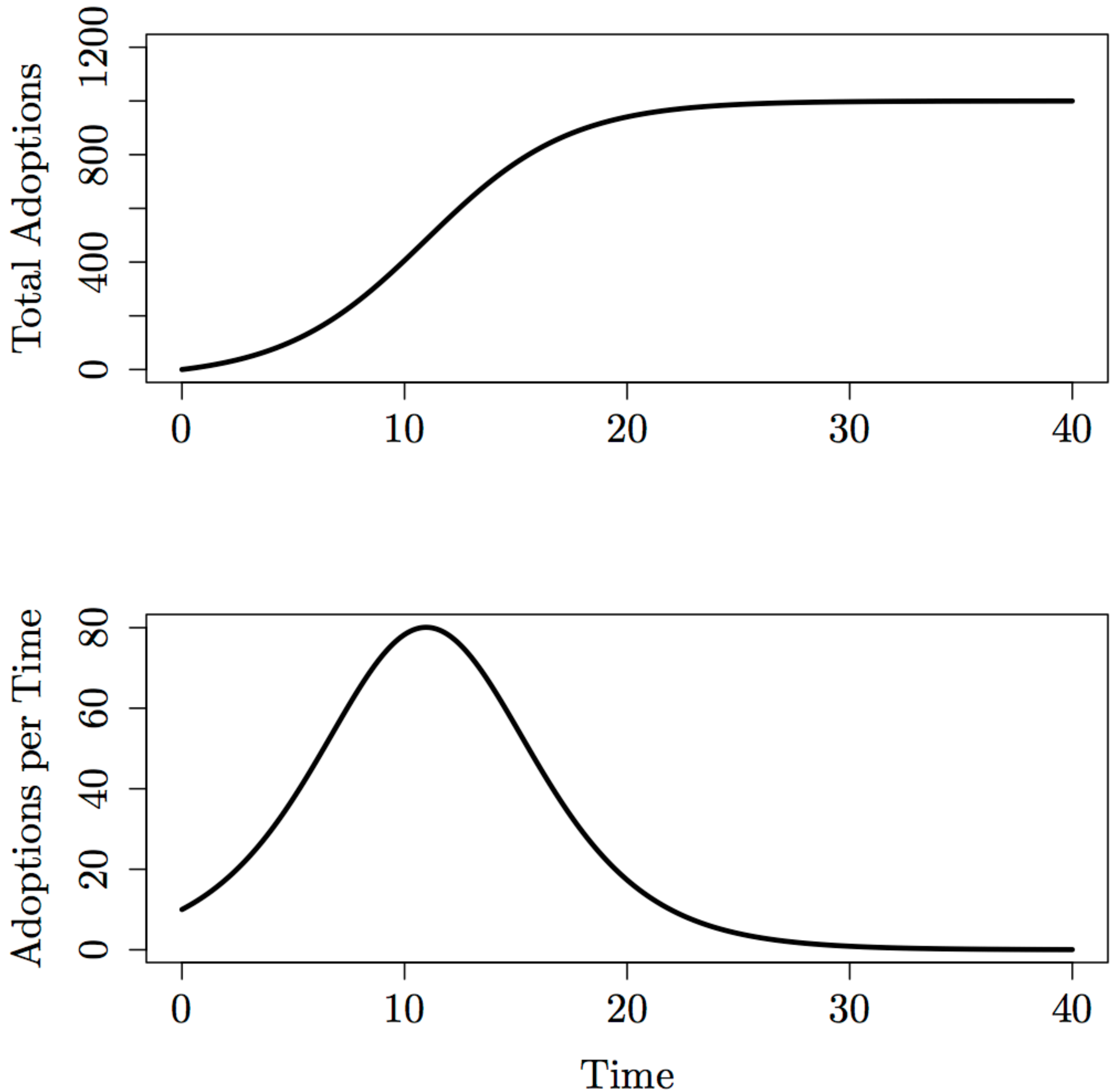
- p is the marketing effect:
  - Constant, dictated by marketing effort of firm.
- $qF(t)$ is the word-of-mouth effect:
  - Increases with increasing proportion of adopted individuals.

Model 1 — Bass

- Solution to Bass's differential equation, assuming initial condition $F(0) = 0$, is

$$F(t) = \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}}$$

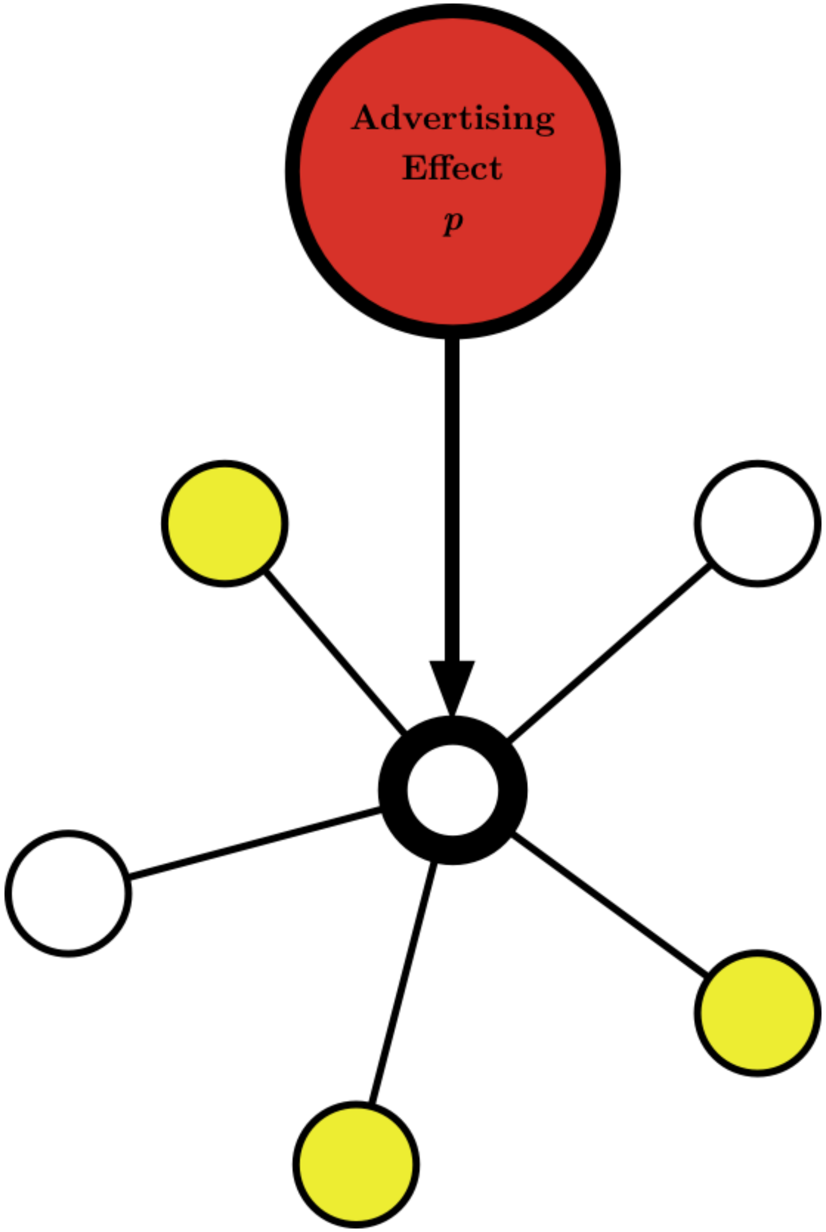
- This adoption curve is logistic-like.


Total Adoptions
0
400
800
1200
0
10
20
30
40
Adoptions per Time
0
20
40
60
80
0
10
20
30
40
Time

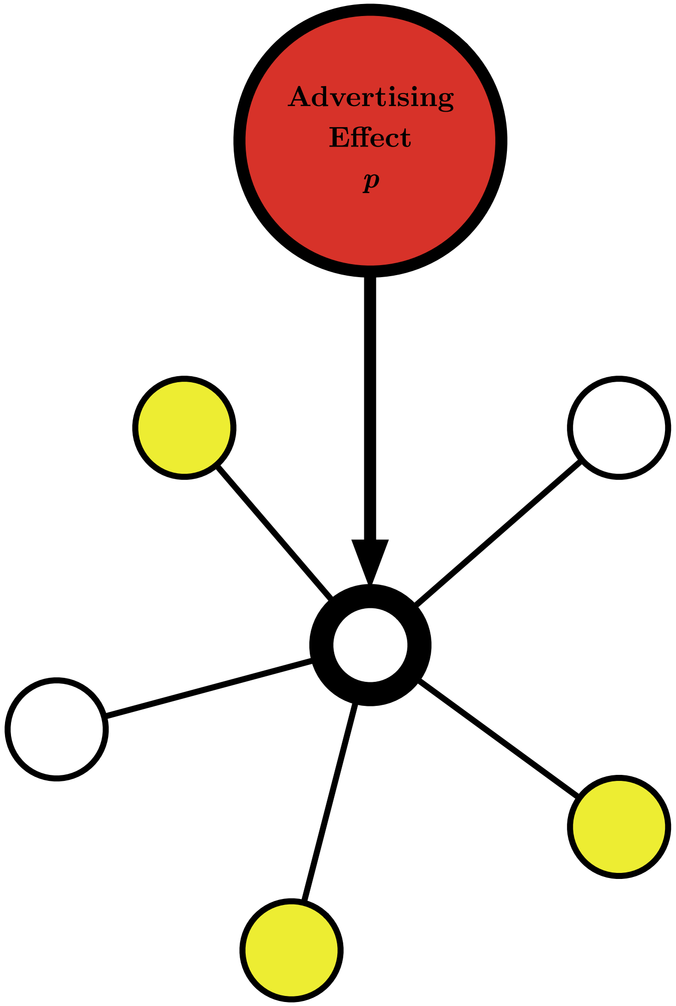
Model 1 — Bass

- We will modify the Bass model by incorporating the *networked nature* of individuals.
  - **New Assumption:** The word-of-mouth effect only works through immediate neighbors in a network.

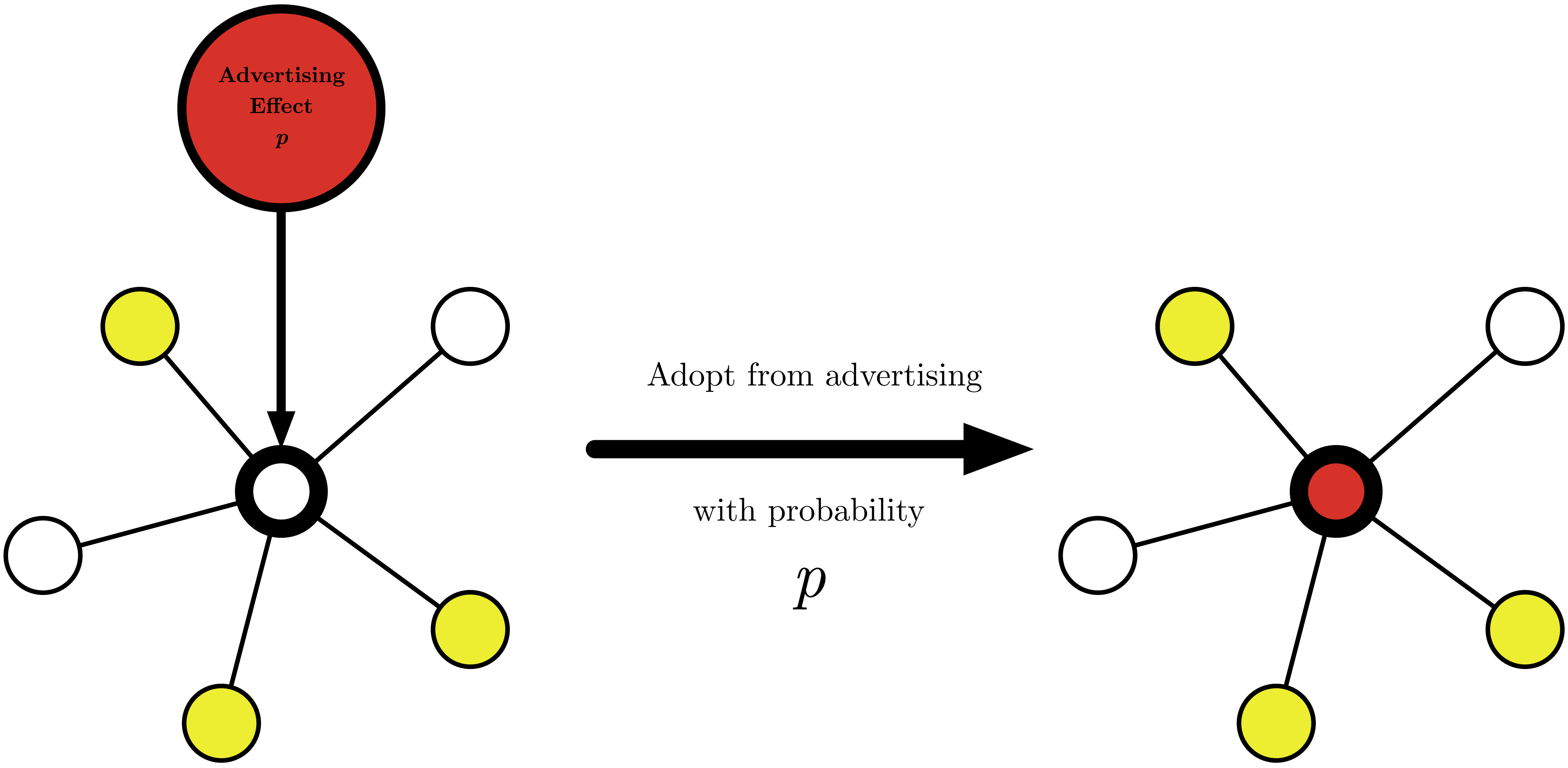
Model 1 — Bass



Model 1 — Bass

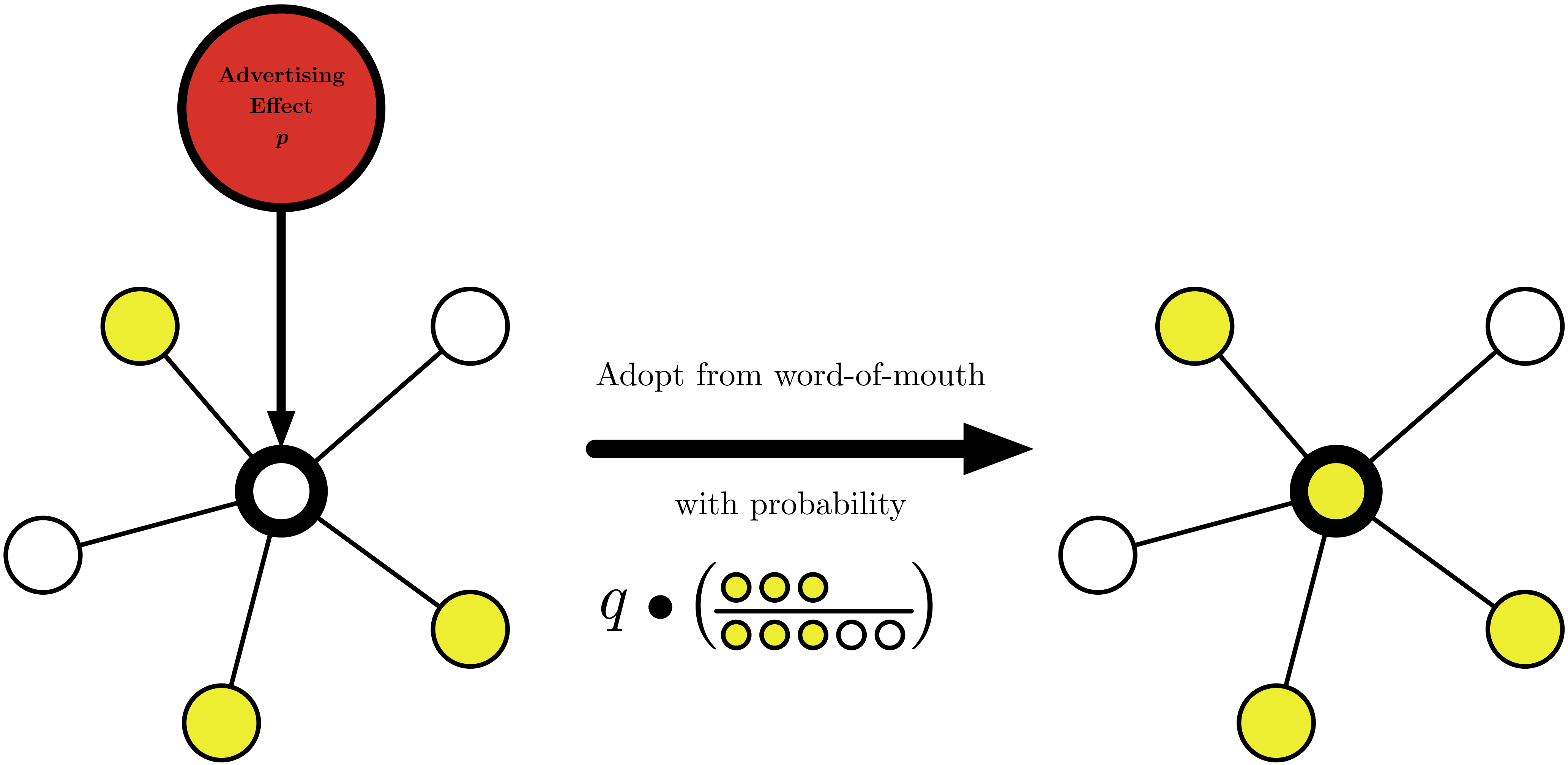


Model 1 — Bass

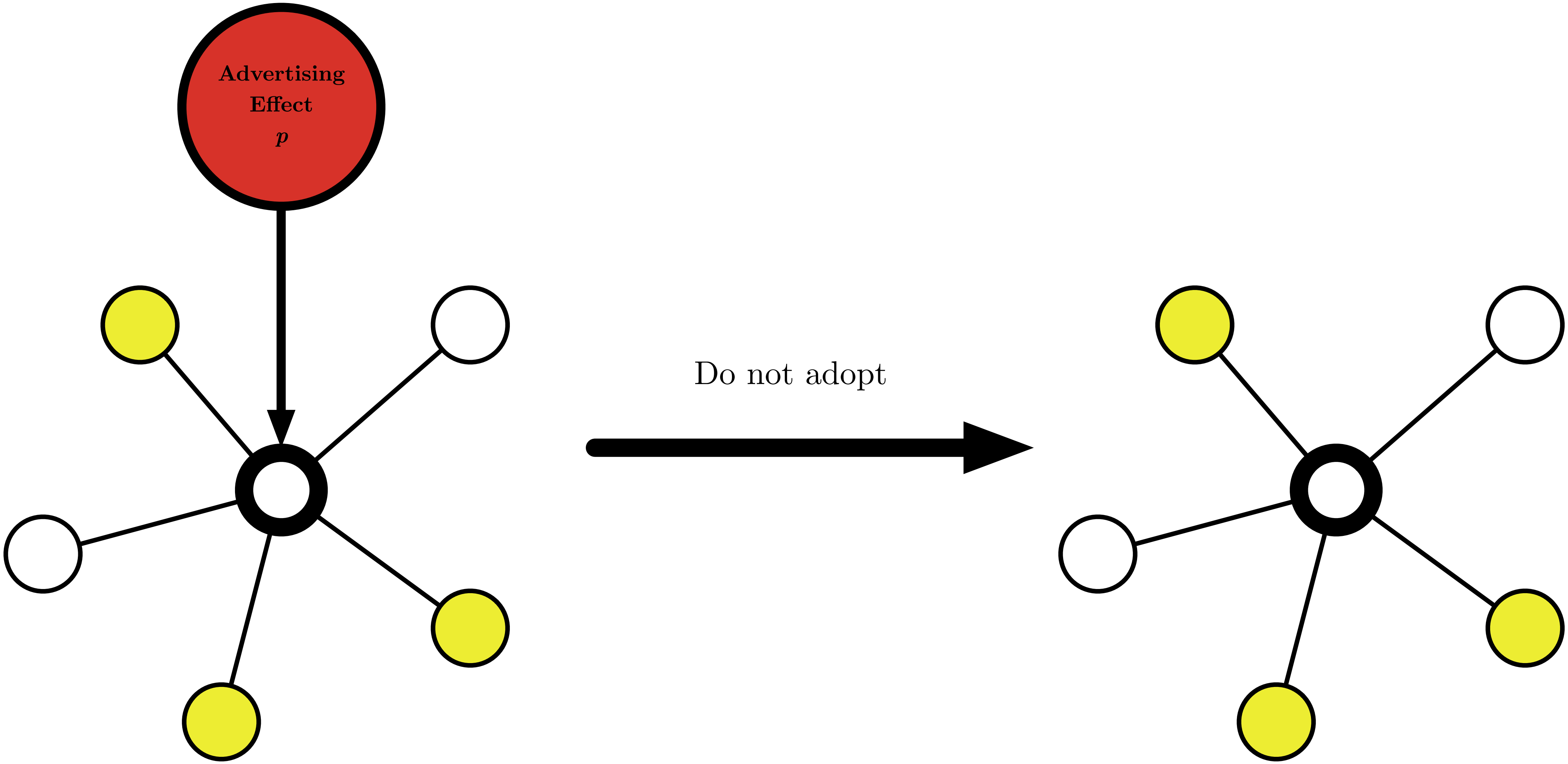


Advertising
Effect
p
Adopt from advertising
with probability
p

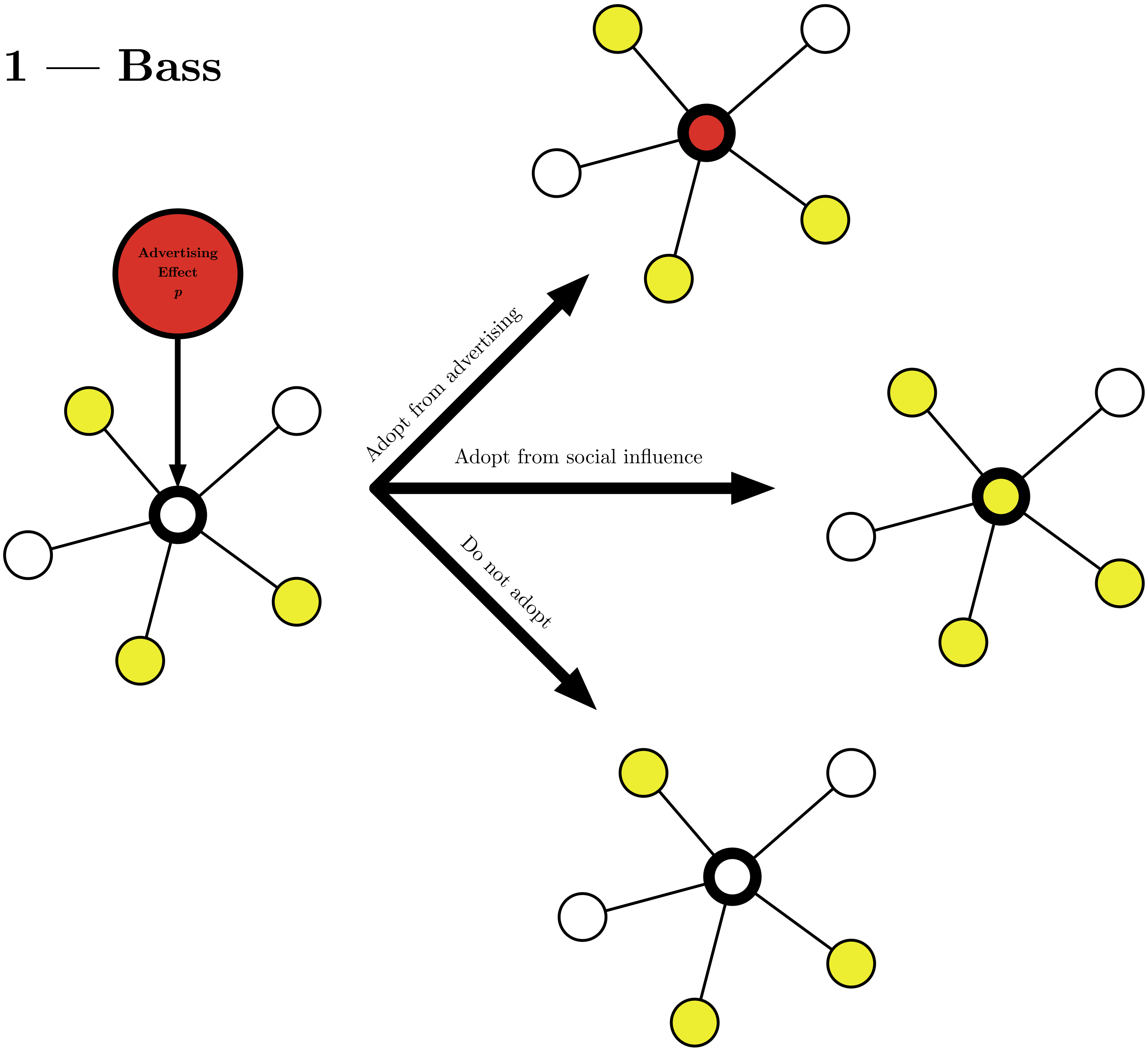
Model 1 — Bass


Advertising
Effect
p
Adopt from word-of-mouth
with probability
q •

Model 1 — Bass



Model 1 — Bass



Advertising
Effect
p
Adopt from advertising
Adopt from social influence
Do not adopt

NetLogo Demo and Explorations

Bass Model Reflections

- How does changing mean degree impact the rate of adoption?
- How does changing the social influence impact the rate of adoption?
- Other observations?

Model 2

—

Linear Threshold

Model 2 — Linear Threshold

- From Mark Granovetter's 1978 paper

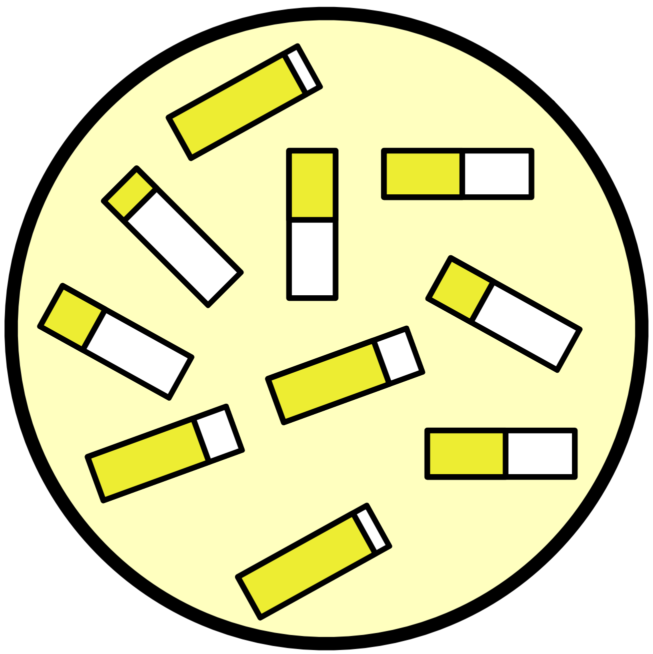
  Threshold Models of Collective Behavior

- A model for binary-choice (binary state) situations:
  - Diffusion of innovation
  - Voting
  - Rumor and disease spread
  - Rioting

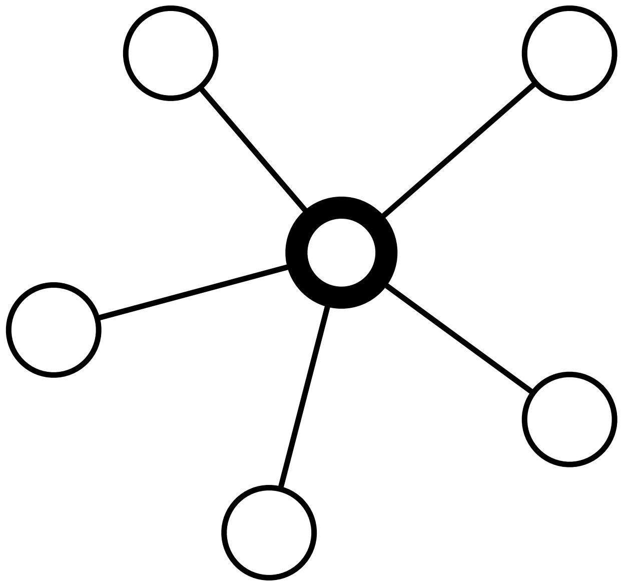
Model 2 — Linear Threshold

- **Assumptions:**
  - An agent's **decision** to adopt is *deterministic*:
    - whenever the proportion of individuals who have adopted crosses the agent's threshold, the agent will adopt.
  - Each agent's **threshold** to adopt is *stochastic*:
    - the threshold is drawn from some underlying statistical distribution *at the start* and remains *fixed*.

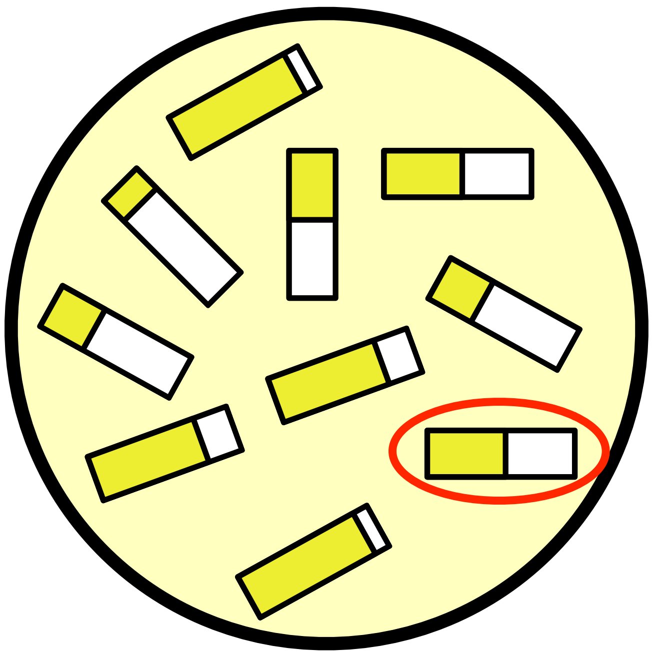
Model 2 — Linear Threshold



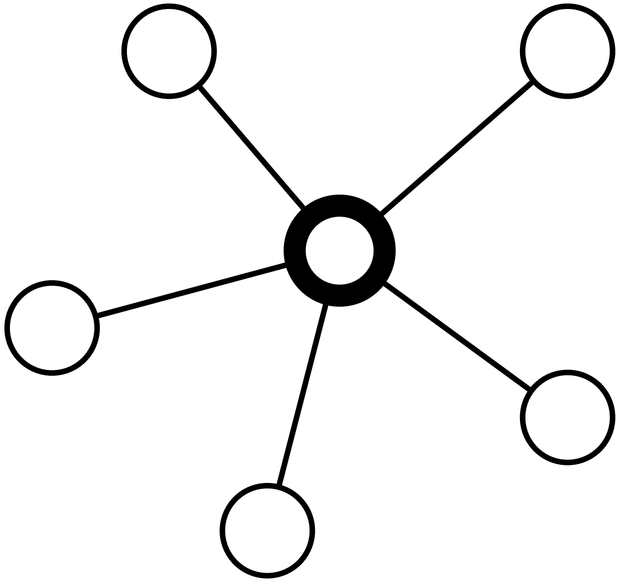
Population of Thresholds



Model 2 — Linear Threshold



Population of Thresholds



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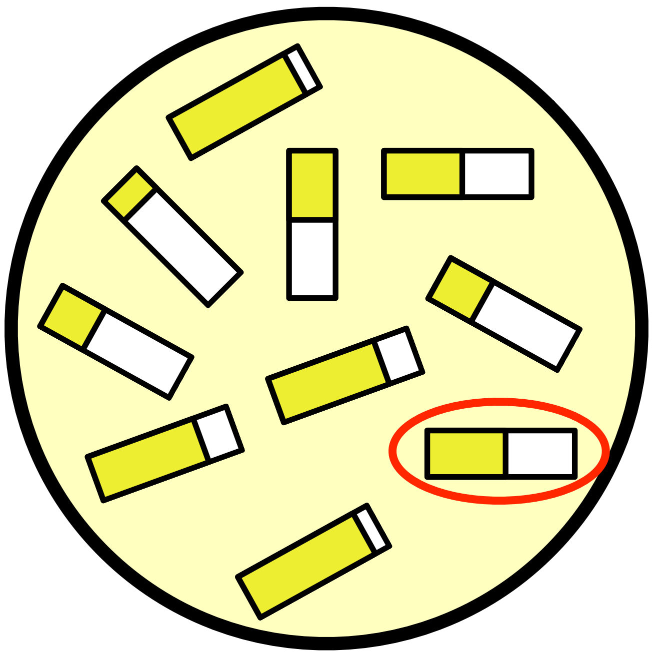
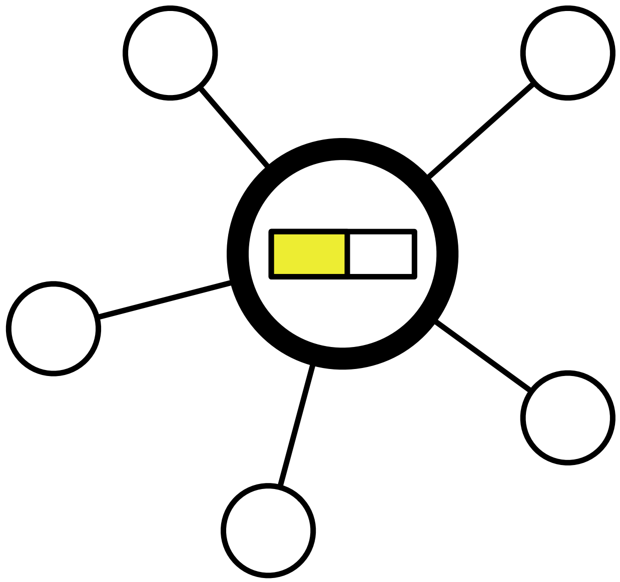


Population of Thresholds



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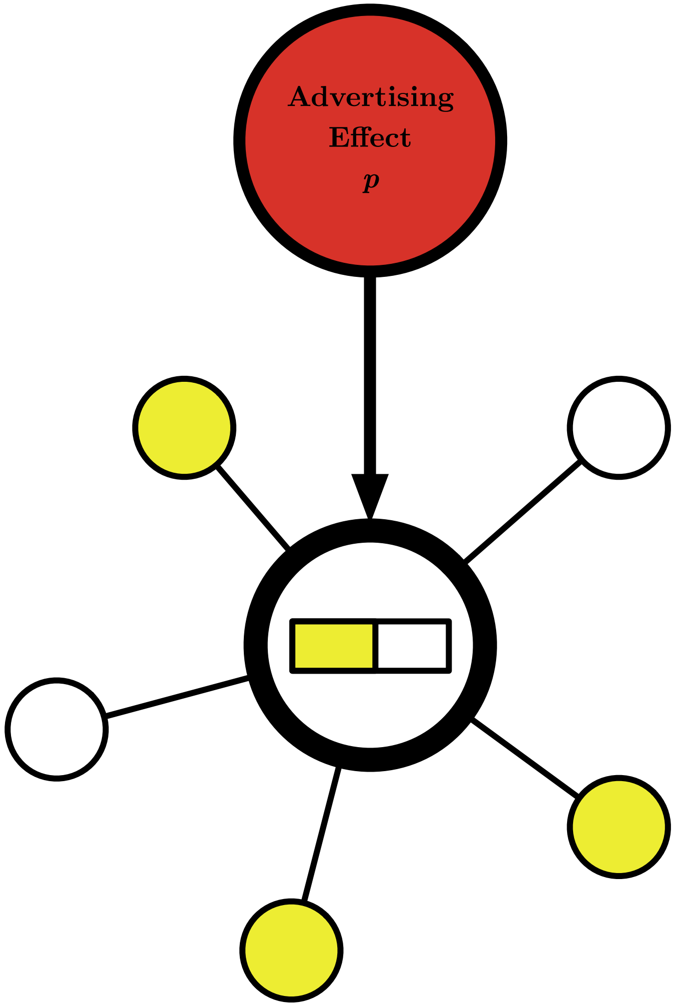

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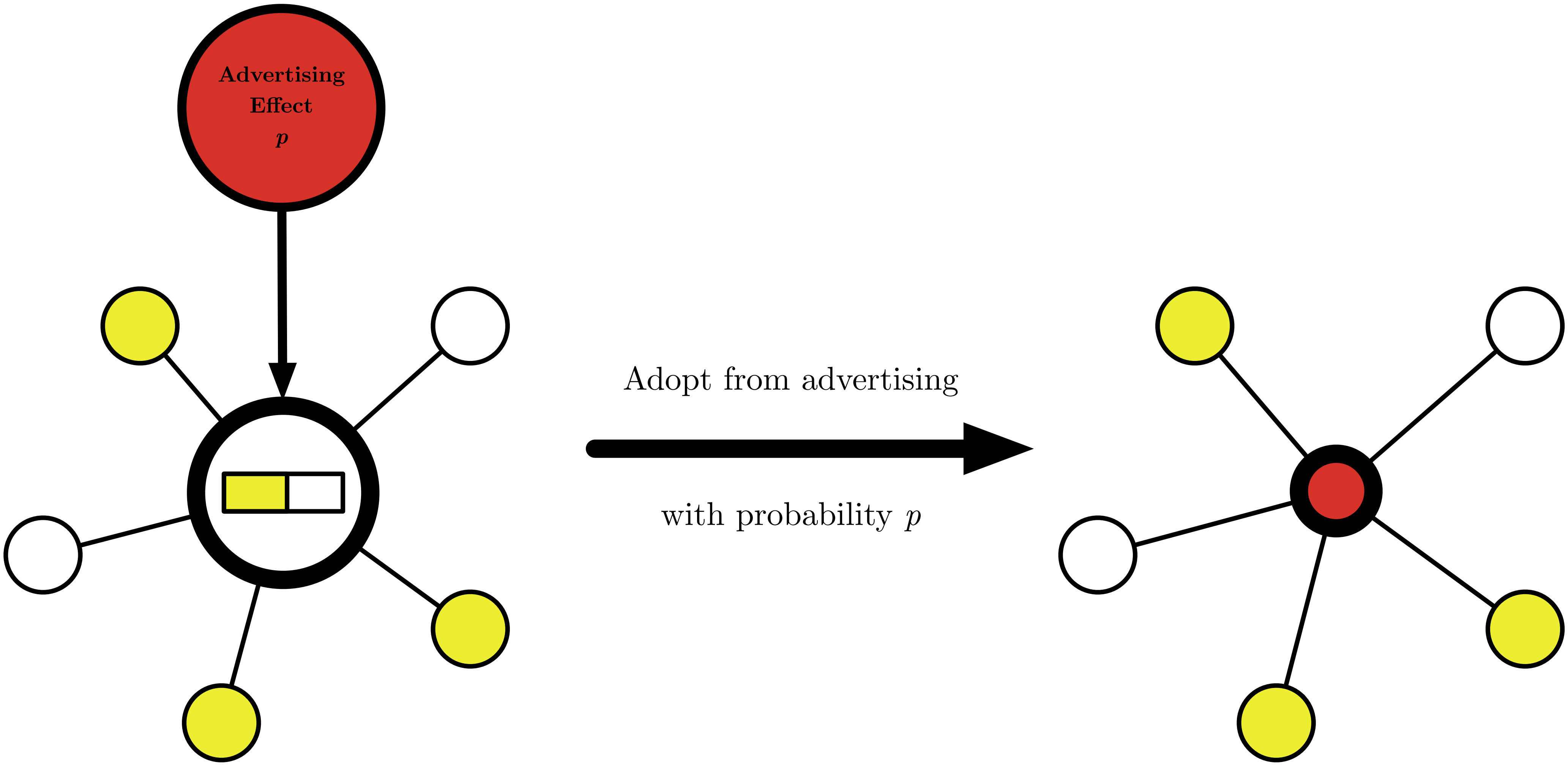
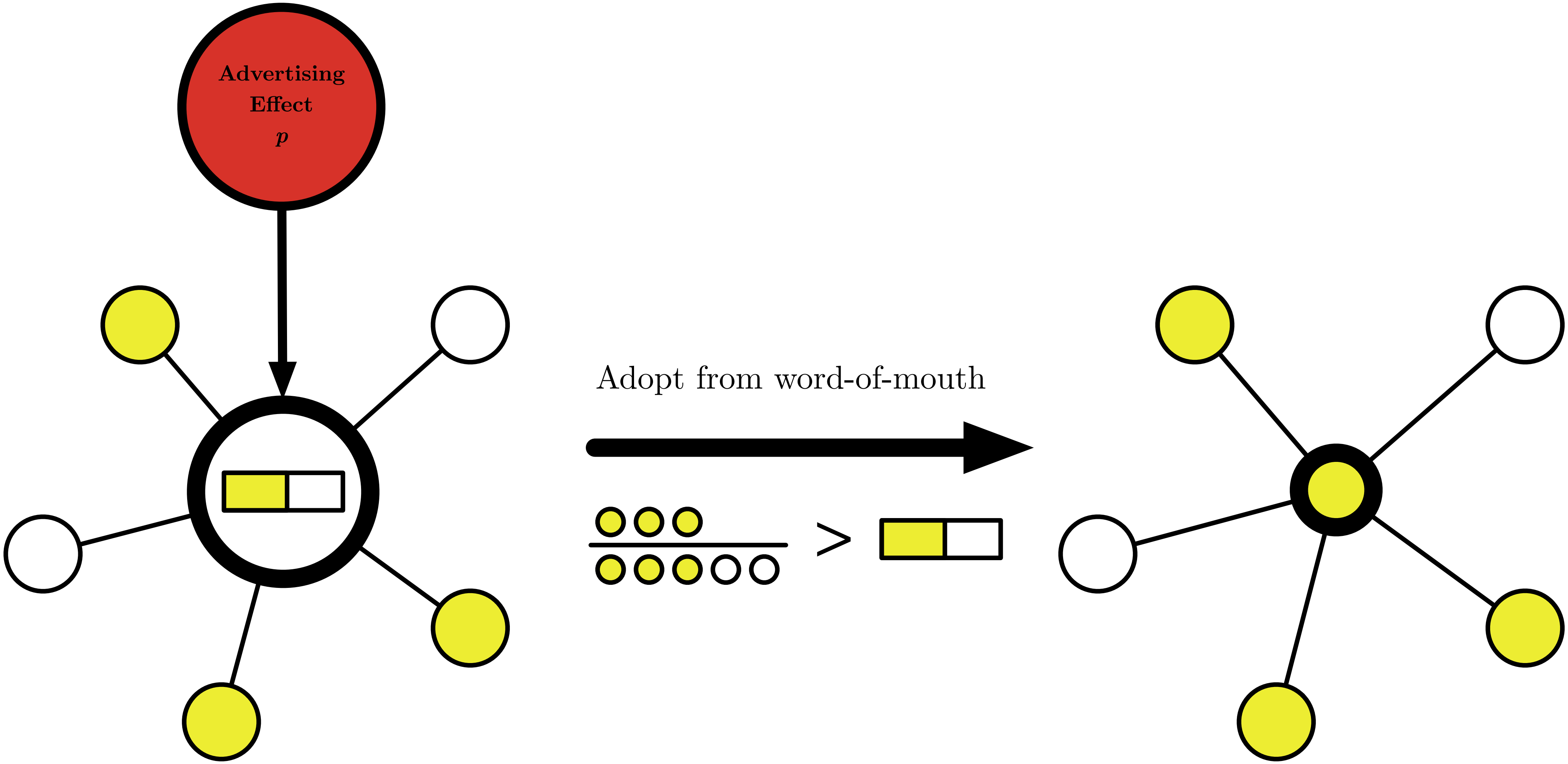
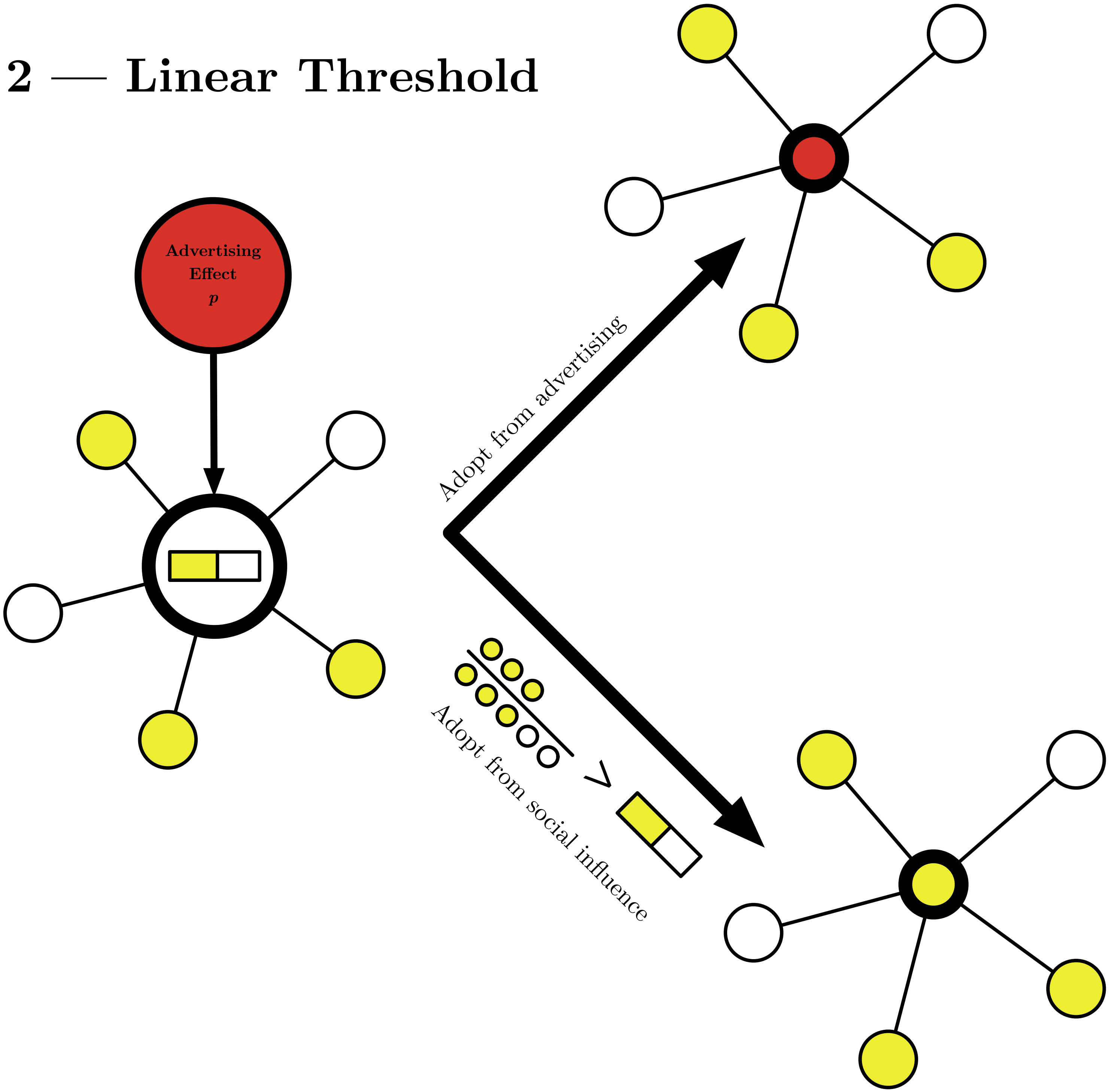


Model 2 — Linear Threshold



Model 2 — Linear Threshold



NetLogo Demo and Explorations

Threshold Model Reflections

- How does the heterogeneity of the threshold distribution affect the tipping point-like behavior?
- How do the threshold distribution and mean degree of the nodes interact?
- How does the network type impact the adoption rate?
- Other observations?

Model 3

—

Independent Cascade

Model 3 — Independent Cascade

- From Jacob Goldenberg, Barak Libai, and Eitan Muller's paper 2001 paper

  Talk of the Network: A Complex Systems Look at the Underlying Process of Word-of-Mouth.

- A word-of-mouth type model, intended to investigate the impact of strong and weak ties on diffusion through a network.
  - In the spirit of Mark Granovetter's *The Strength of Weak Ties* (1973)

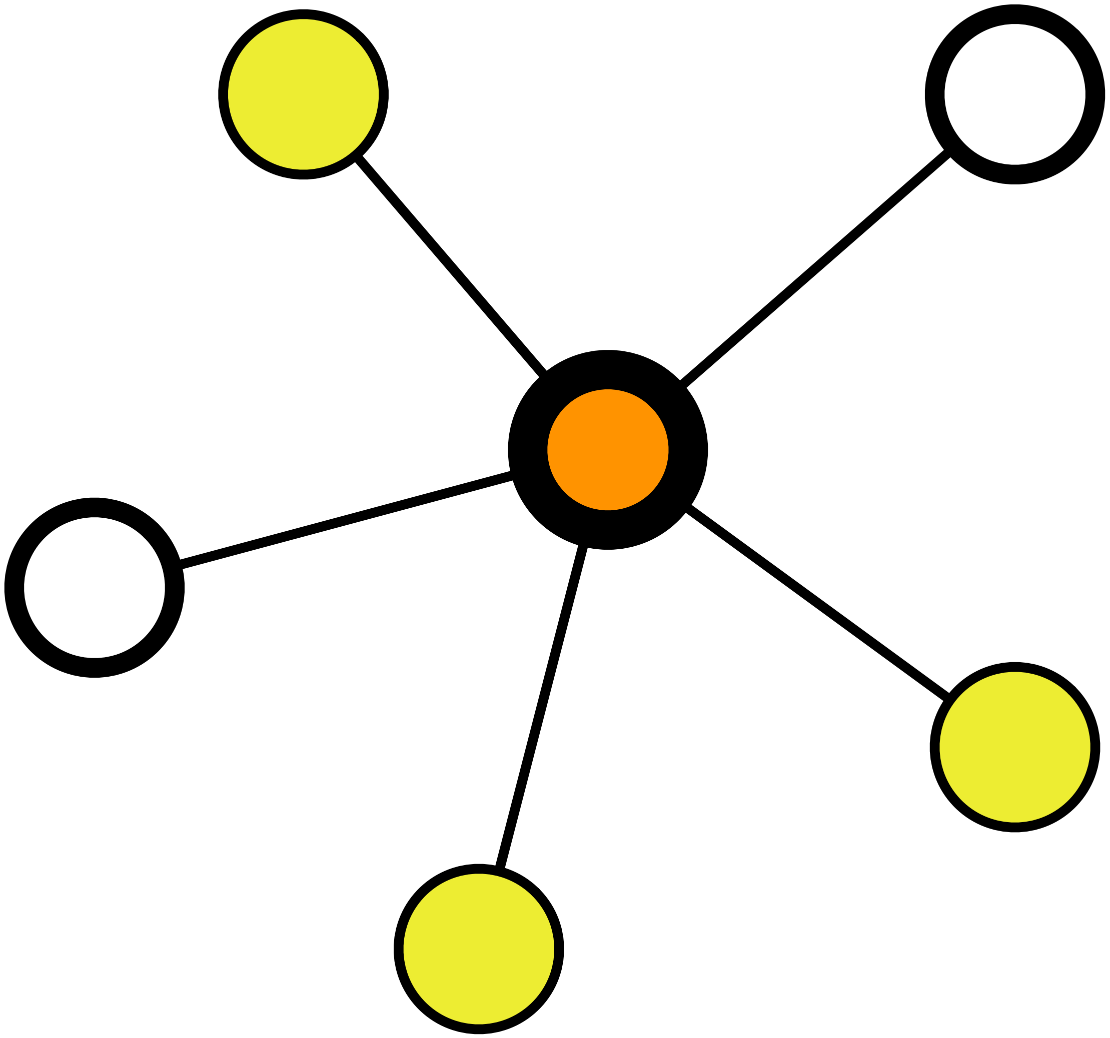
Model 3 — Independent Cascade

- Similar to Bass in that nodes adopt based on a *stochastic* rule.

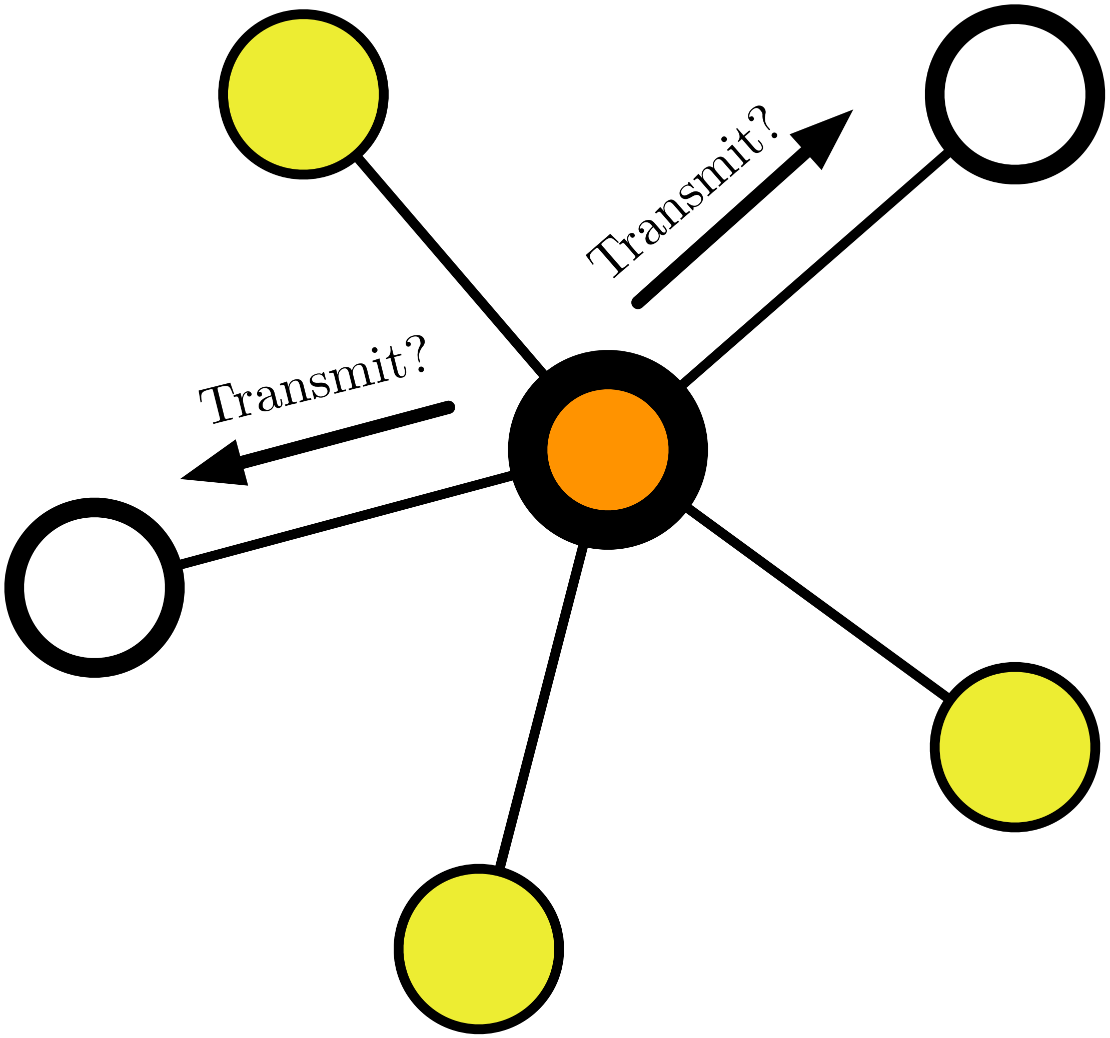
- Different from Bass in that:
  - Focus on a node *passing* adoption to neighbor nodes.

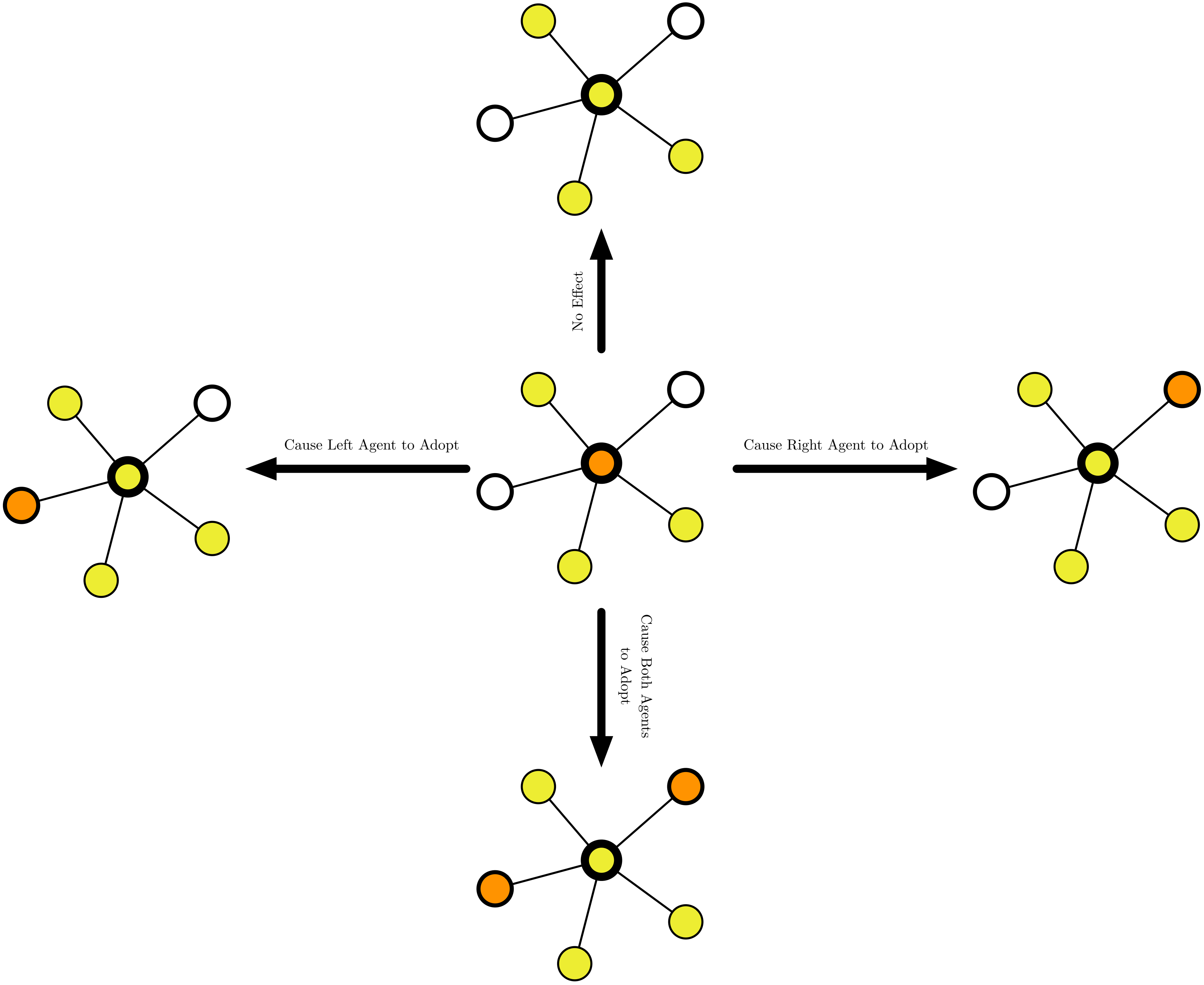
  - Each node only gets a single chance to pass adoption to each of its neighbors.

Model 3 — Independent Cascade



Model 3 — Independent Cascade




No Effect
Cause Left Agent to Adopt
Cause Right Agent to Adopt
Cause Both Agents to Adopt

Model 3 — Independent Cascade

- Also include advertising effect, so a node adopts with probability p even if they were not transmitted to.

NetLogo Demo and Explorations

Independent Cascade Reflections

- How did the cascade behave when the broadcast influence was zero?
- Did you find a value of social influence that was very likely to lead to network-wide adoption, even with the broadcast influence set to zero?
- How did the size of the initial cascade depend on the number of seed adopters in the network?
- Other observations?

Model Selection from Observed Data

Model Selection from Observed Data

- Real world network.
  - 4039 Facebook users

- 'Observed' (simulated) data.
  - 20 time series of adoption

- Can we identify which model, and what parameters, might have given rise to these adoption time series?

Models of Network Structure

Model 1

—

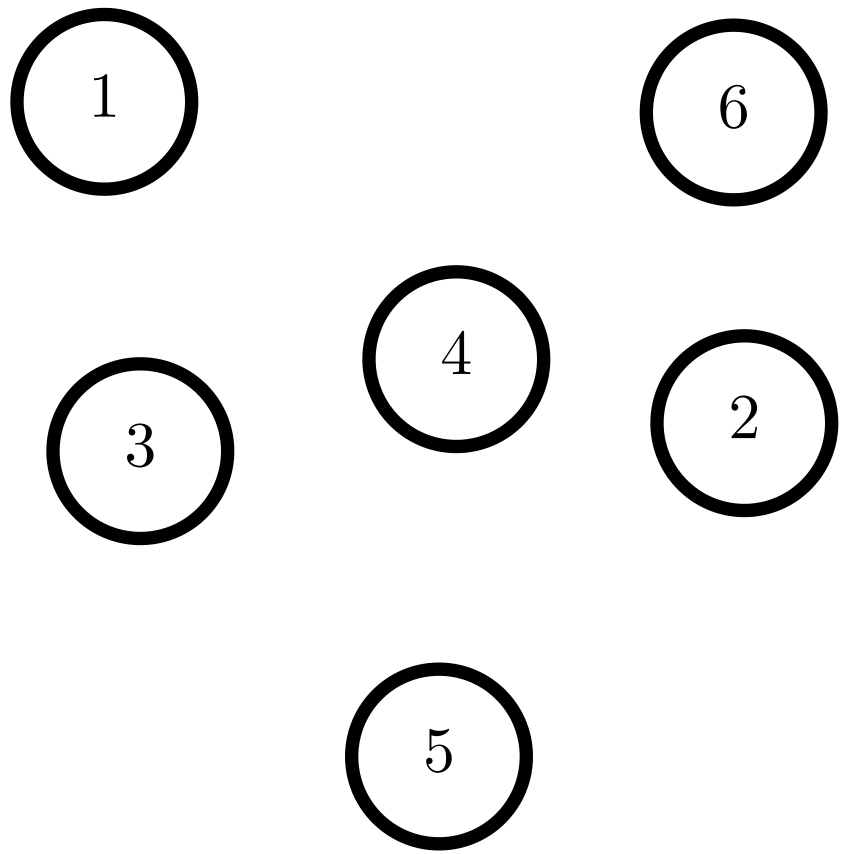
Erdős-Rényi

Model 1 — Erdős-Rényi

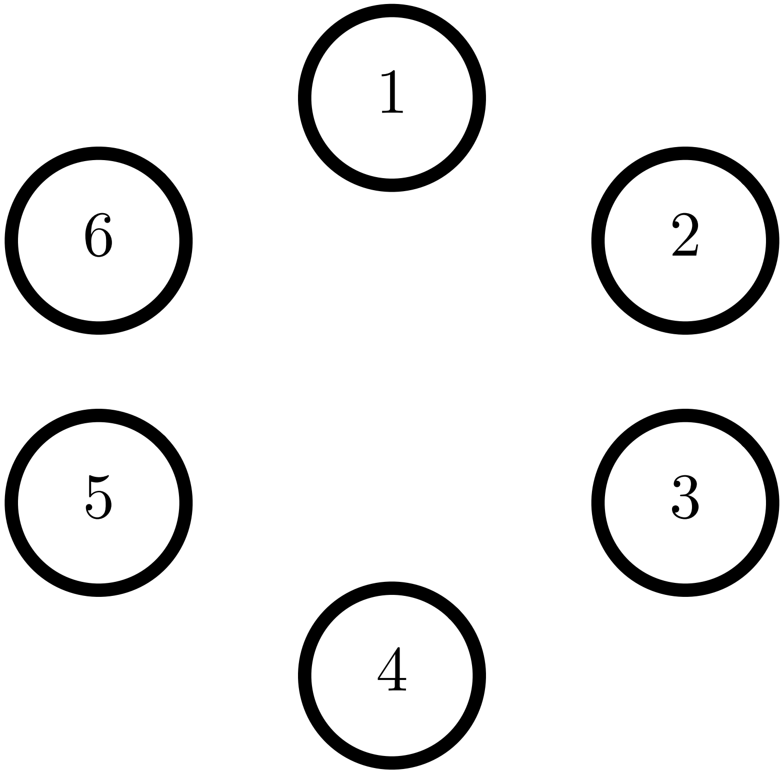
- Developed by Paul Erdős and Alfréd Rényi in 1959.

- A model of a 'completely random' network, where each possible edge in the network occurs independently of all the others with a fixed probability p.

Model 1 — Erdős-Rényi



Model 1 — Erdős-Rényi



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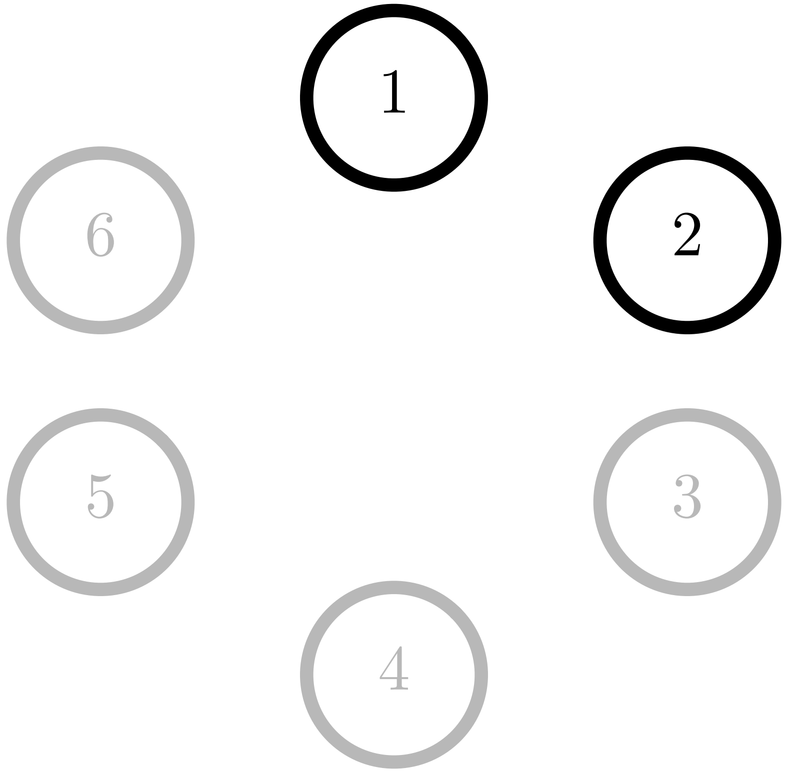

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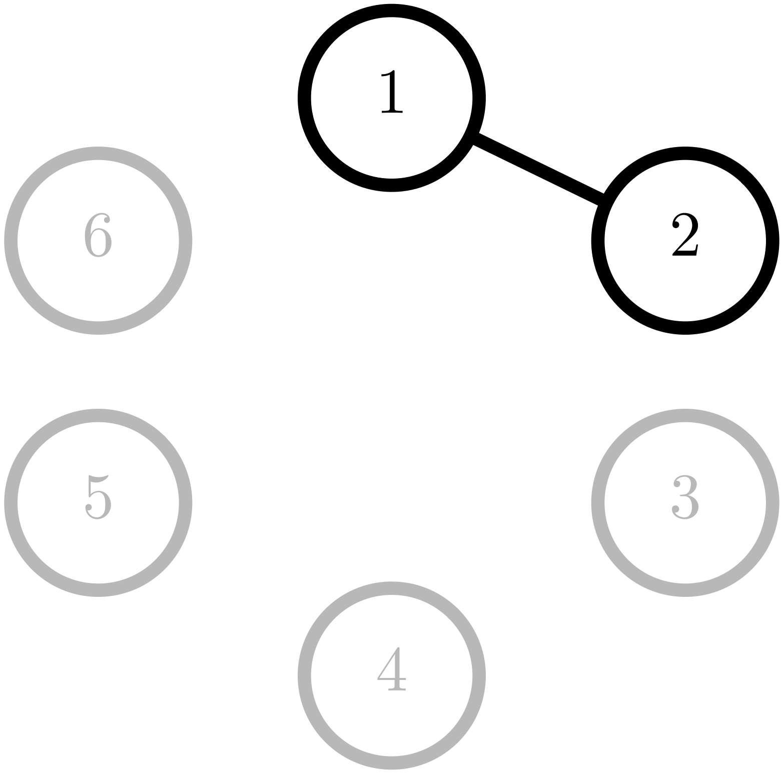
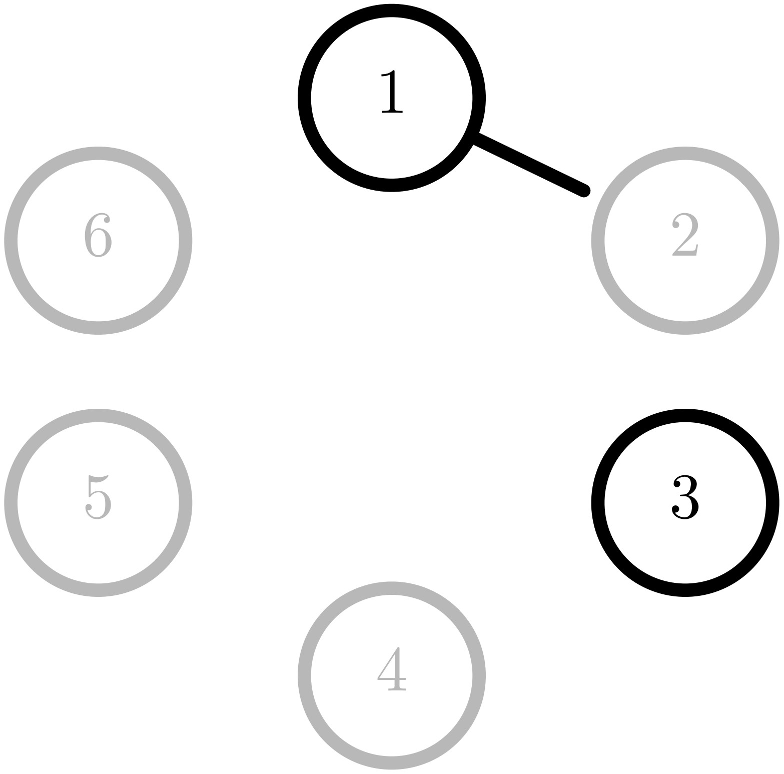


Model 1 — Erdős-Rényi



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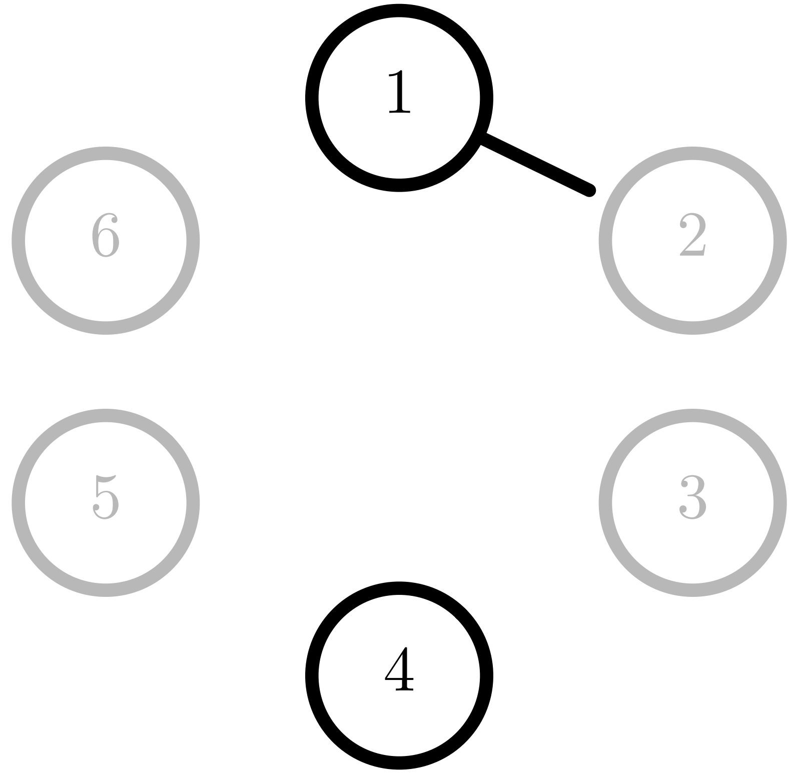

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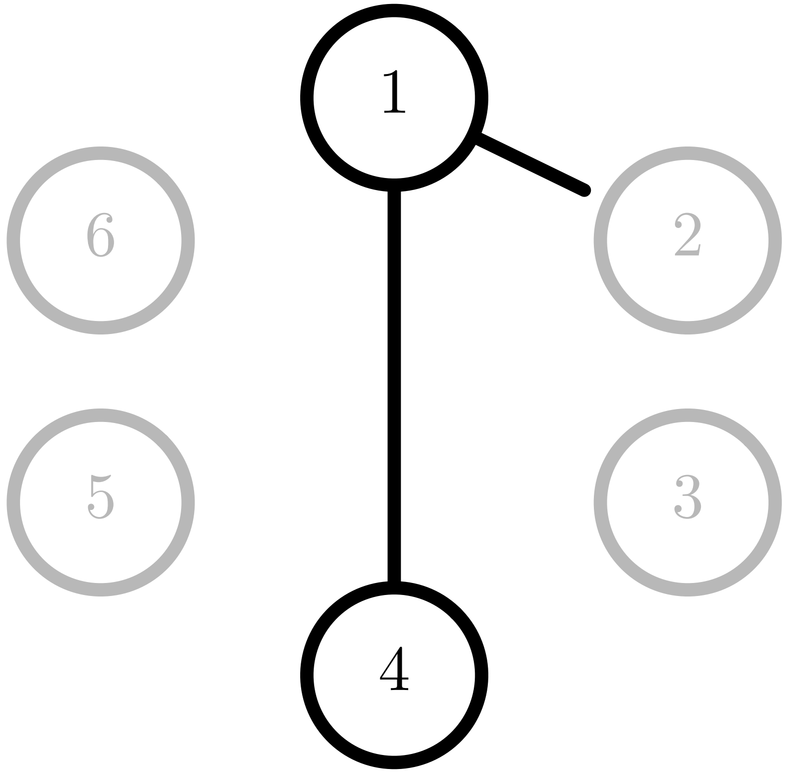

Model 1 — Erdős-Rényi

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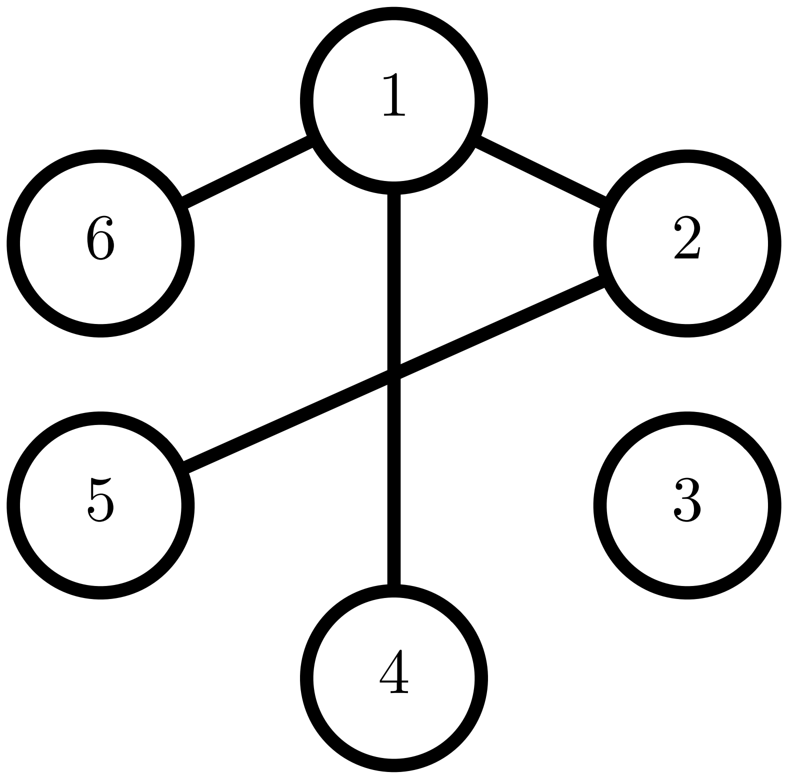
Model 1 — Erdős-Rényi



Model 2

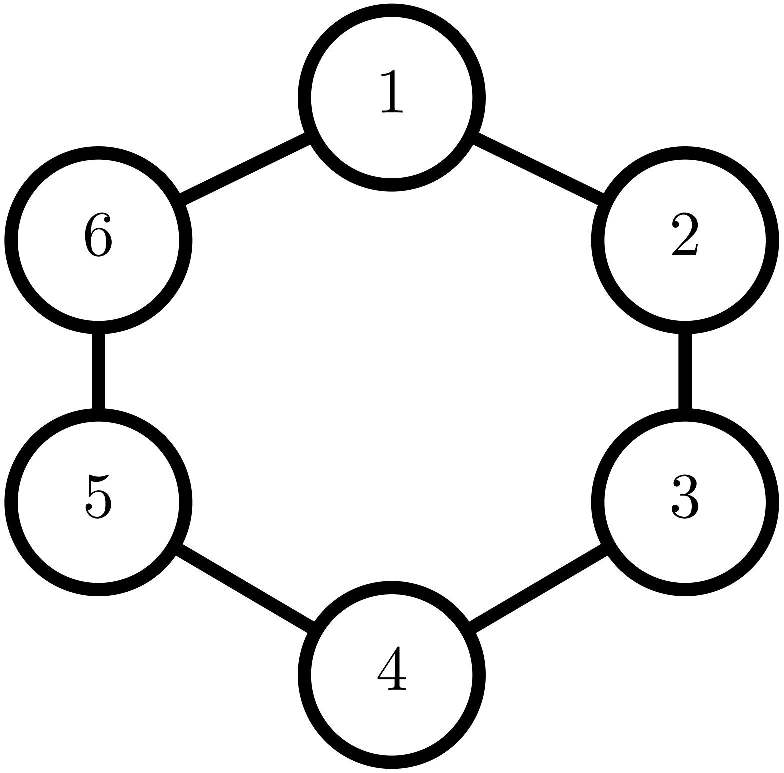
—

Watts-Strogatz

Model 2 — Watts-Strogatz

- Developed by Duncan Watts and Steve Strogatz in 1998.
- A model of ‘small world’ networks.
- Begin with a ring network, with each node connected to the $K/2$ nearest neighbors on each side.
- For each node in the network, for each original ring edge, rewire to a different terminal node with probability β, avoiding self-loops and multi-edges.

Model 2 — Watts-Strogatz



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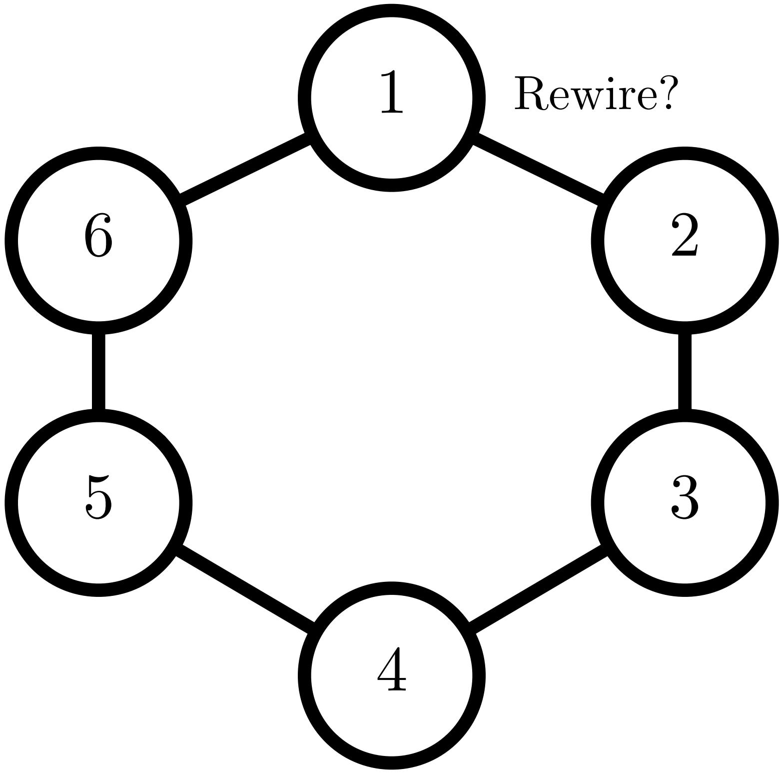

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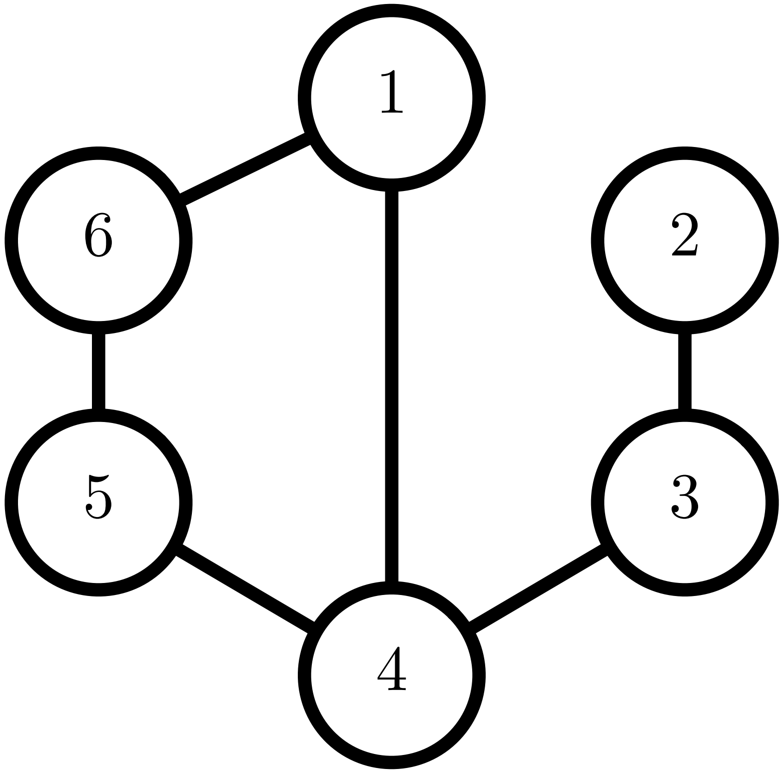

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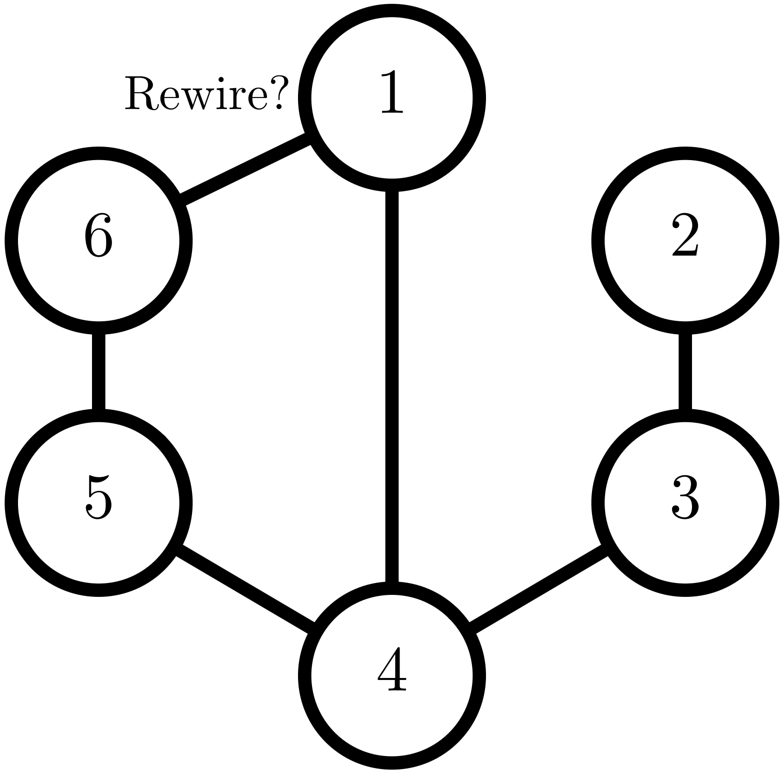

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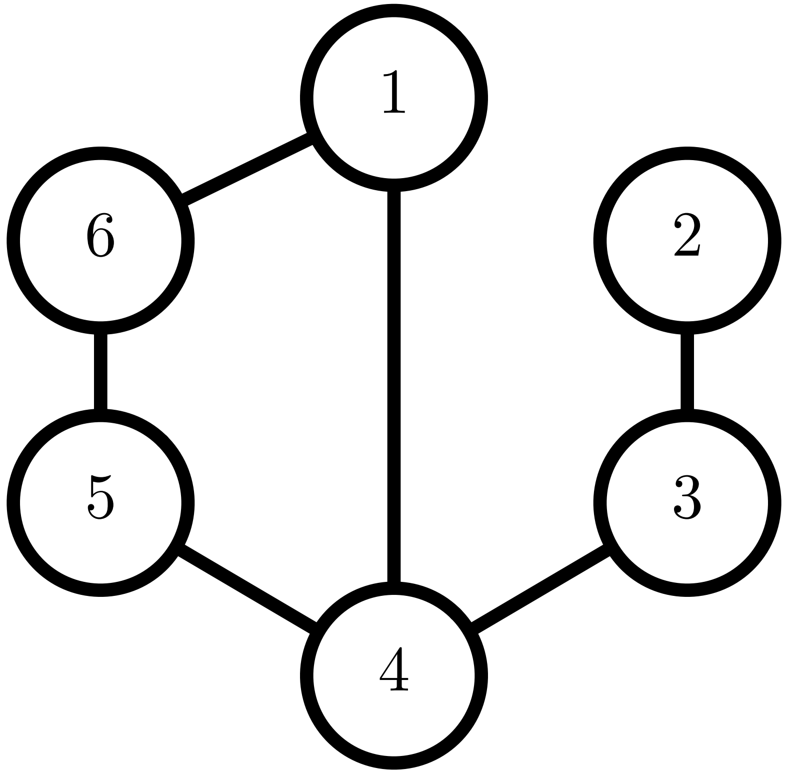

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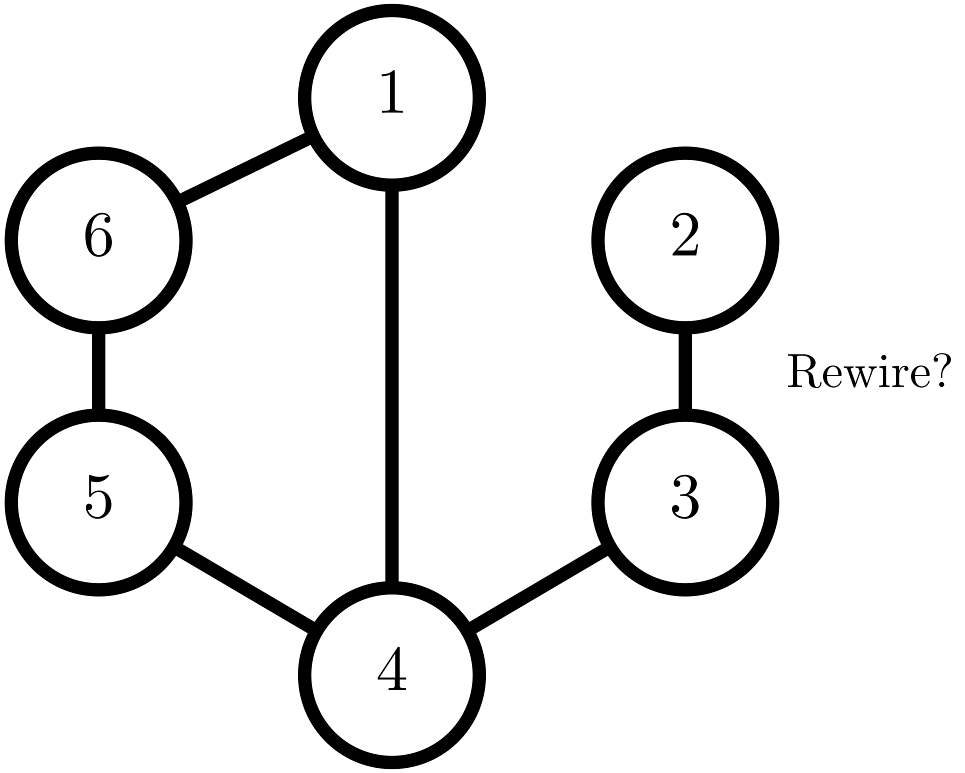

Model 1 — Erdős-Rényi

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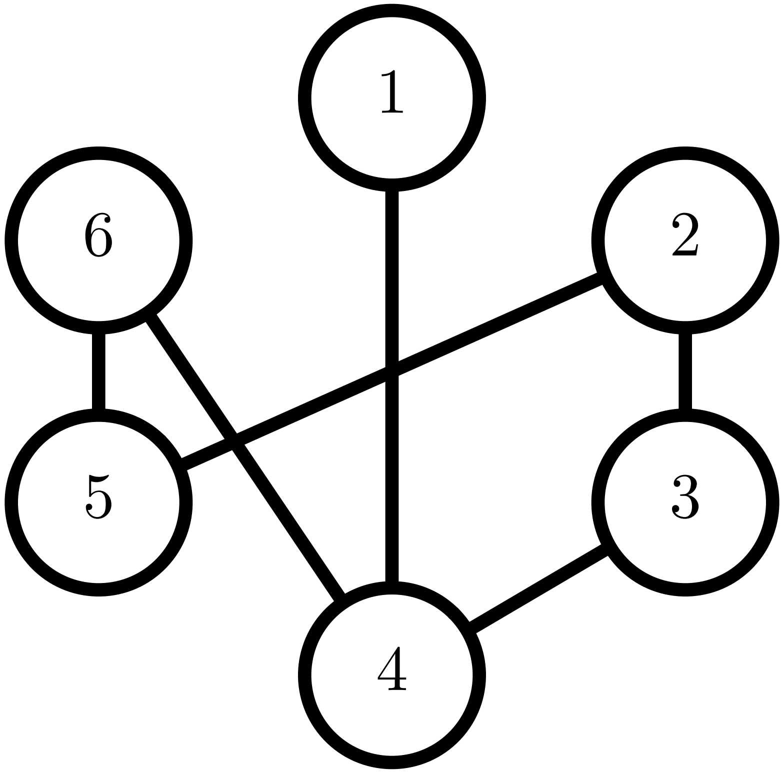
Model 2 — Watts-Strogatz



Model 3

—

Preferential Attachment

Model 3 — Preferential Attachment

- A model of network growth popularized by Albert-László Barabási and Réka Albert in 1999.

- A growth model for networks.

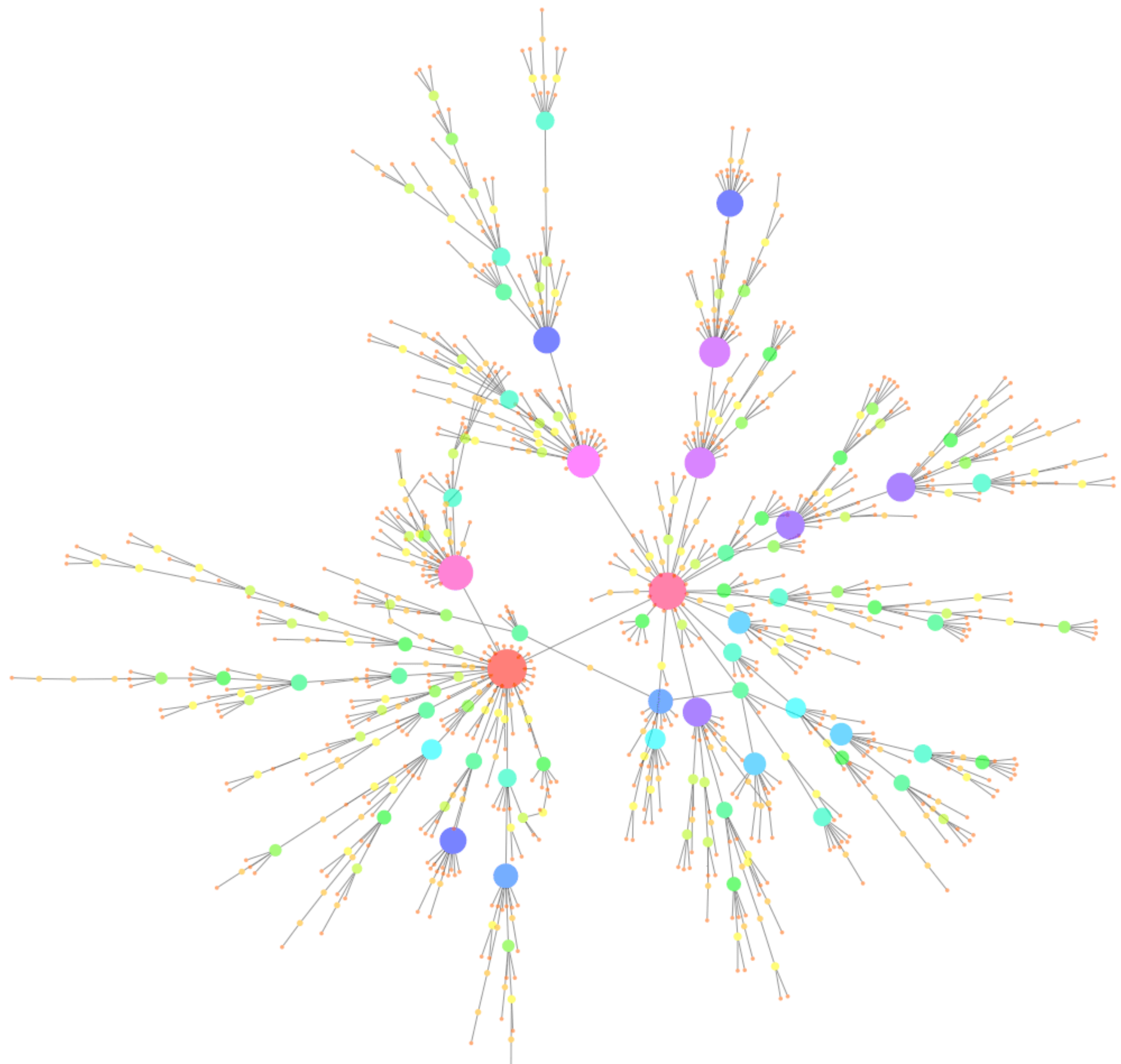
- Modeled after the Matthew Effect:
    - 'The rich get richer.'

Model 3 — Preferential Attachment

- At each iteration, add a new node and connect it with a single edge to one of the existing nodes.

- Choose the existing node with a probability proportional to the degree of the existing node.
    - High degree nodes will be more likely to get a new edge, and will increase their degree.
    - Low degree nodes will be unlikely to get a new edge, and will retain their low degree.

Model 3 — Preferential Attachment



Hands-On

github.com/ddarmon/sfinsc-day2