

The Friendship Paradox

Social Networks Analysis and Graph Algorithms

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- Sampling nodes and edges
- Average degree of friends

Sources

- Albert-László Barabási: Network Science. Cambridge University Press, 2016 (chapter 4)
- Filippo Menczer, Santo Fortunato, and Clayton A. Davis. A First Course in Network Science. Cambridge University Press, 2020 (chapter 3).
- URLs cited in the footer of specific slides

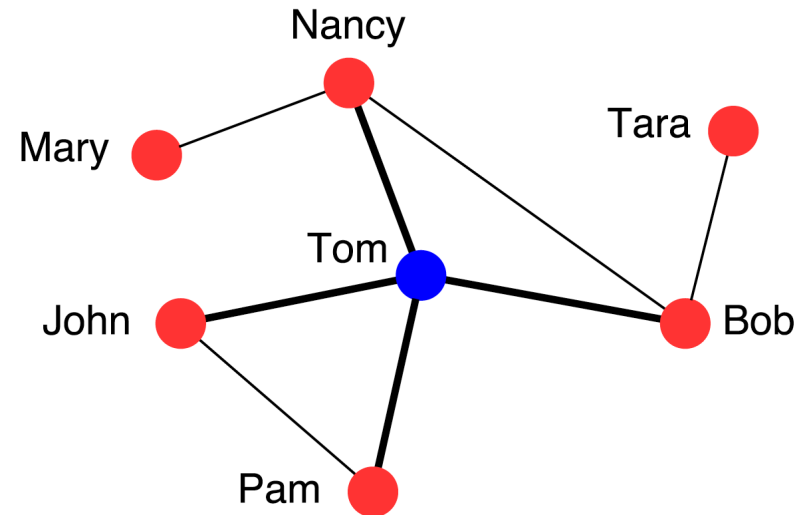
Sampling a random node

vs

**sampling at random one of the two nodes
attached to a random edge**

Exercise

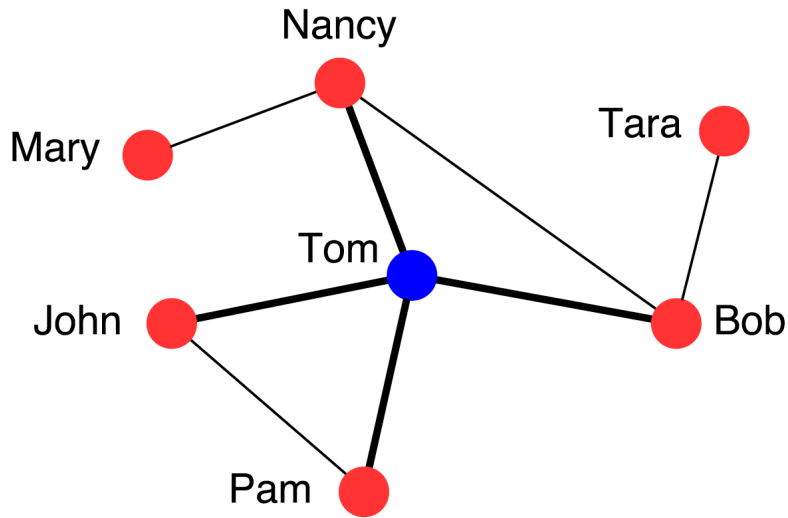
- What is the probability of selecting Tom if we select a random node?
- What is the probability of selecting Tom if we select a random edge and then randomly one of the two nodes attached to it?
- Answer numerically with a simplified fraction



Answer in Nearpod Collaborate
<https://nearpod.com/student/>
Access to be provided during class

Sampling a random node
vs
sampling a random friend
of a random node

Average degree of friends



- Average degree
$$(1 + 3 + 3 + 1 + 4 + 2 + 2)/7 = 16/7 \approx 2.29$$
- Average degree of friends of:
 - Mary: 3
 - Nancy: $(1+4+3)/3 = 8/3$
 - Tara: 3
 - Bob: $(1+3+4)/3 = 8/3$
 - Tom: $(3+3+2+2)/4 = 10/4$
 - John: $(4+2)/2 = 3$
 - Pam: $(4+2)/2 = 3$
 - Average degree of friends ≈ 2.83 (> 2.29)

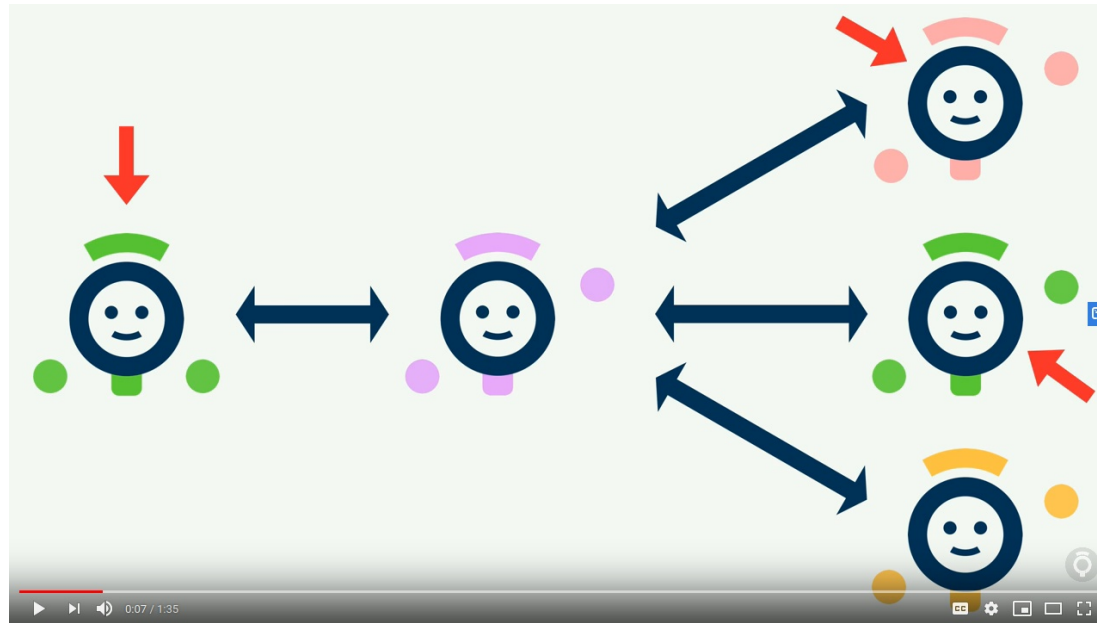
The friendship paradox

- Take a random person x ; what is the expected degree of this person? $\langle k \rangle$
- Take a random person x , now pick one of x 's neighbors, let's say y ; what is the expected degree of y ?

It is not $\langle k \rangle$

- This “paradox” is a useful vaccination strategy

Sampling bias and the friendship paradox (1'35'')



<https://www.youtube.com/watch?v=httLvVufAYs>

Imagine you're at a random airport on earth

- Is it more likely to be ...
a large airport or a small airport?
- If you take a random flight out of it ...
will it go to a large airport or a small airport?

An example of friendship paradox

- Pick a random airport on Earth
 - Most likely it will be a small airport
- However, no matter how small it is, it **will** have flights to big airports
- On average those airports will have much larger degree



Time	Flight	Airline	Destination	Gate	Exp.	Remarks
11:00	KA 376	DRAGONAIR	Hong Kong	4		Chk-in closed
12:25	DG 7792	tigerair	Singapore	1		On Time
12:25	QR 931	QATAR	Doha, Qatar	5		On Time
17:40	EK 339	Emirates	Dubai	5		On Time
00:50	OZ 708	ASIANA AIRLINES	Seoul Incheon	5		On Time
07:05	5J 150	JAL	Hong Kong	1		On Time
07:20	DG 7924	tigerair	Hong Kong	1		On Time
08:00	DG 7792	tigerair	Singapore	1		On Time
12:10	5J 537	JAL	Singapore	1		On Time
12:25	QR 931	QATAR	Doha, Qatar	5		On Time

Exercise [B. 2016, Ex. 4.10.2]

"Friendship Paradox"

- Remember p_k is the probability that a node has k "friends"
- If we randomly select a link, the probability that a node at any end of the link has k friends is $q_k = C k p_k$ where C is a normalization factor
 - (a) Find C (the sum of q_k must be 1)

Answer in Nearpod Collaborate
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Exercise [B. 2016, Ex. 4.10.2]

"Friendship Paradox"

- If we randomly select a link, the probability that a node at any end of the link has k friends is

$q_k = C k p_k$ where C is a normalization factor

- q_k is also the prob. that a randomly chosen node has a neighbor of degree k

(b) Find its expectation $E[q_k]$ which we will call $\langle k_F \rangle$

Remember
$$E[X] = \sum_{X_{\min}}^{X_{\max}} x \cdot P(X = x)$$

Exercise [B. 2016, Ex. 4.10.2]

"Friendship Paradox"

(c) Compute the expected number of friends of a neighbor of a randomly chosen node in the case below

(d) compare with the expected number of friends of a randomly chosen node

$$N = 10000$$

$$\gamma = 2.3$$

$$k_{\min} = 1$$

$$k_{\max} = 1000$$

$$\langle k^n \rangle = C \frac{k_{\max}^{n-\gamma+1} - k_{\min}^{n-\gamma+1}}{n - \gamma + 1}$$

$$C = (\gamma - 1) k_{\min}^{\gamma-1}$$

Code

```
def degree_moment(kmin, kmax, moment, gamma):  
    C = (gamma-1.0)*(kmin**(gamma-1.0))  
    numerator = (kmax**(moment-gamma+1.0) - kmin**(moment-gamma+1.0))  
    denominator = (moment-gamma+1.0)  
    return C * numerator / denominator
```

```
kavg = degree_moment(kmin=1, kmax=1000, moment=1, gamma=2.3)  
print(kavg)
```

3.787798988222529

```
ksqavg = degree_moment(kmin=1, kmax=1000, moment=2, gamma=2.3)  
print(ksqavg)
```

231.94329076177414

```
print(ksqavg / kavg)
```

61.23431879119234

Summary

Practice on your own

- Draw a small graph, and sample from that graph until you're convinced $\langle k_F \rangle > \langle k \rangle$