

# The Friendship Paradox

## Social Networks Analysis and Graph Algorithms

Prof. Carlos “ChaTo” Castillo — <https://chato.cl/teach>



Universitat  
Pompeu Fabra  
*Barcelona*

# Contents

- Sampling nodes and edges
- Average degree of friends

# Sources

- A. L. Barabási (2016). Network Science – Chapter 04
- F. Menczer, S. Fortunato, C. A. Davis (2020). A First Course in Network Science – Chapter 03
- URLs cited in the footer of specific slides

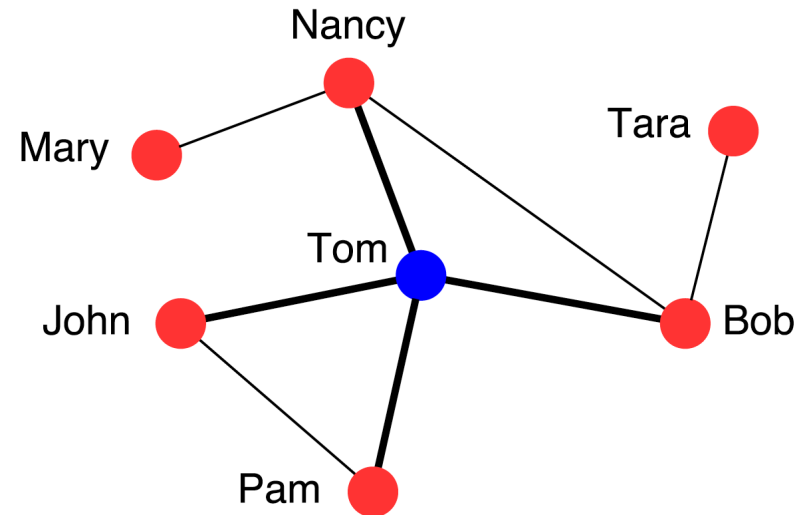
**Sampling a random node**

**vs**

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

# Exercise

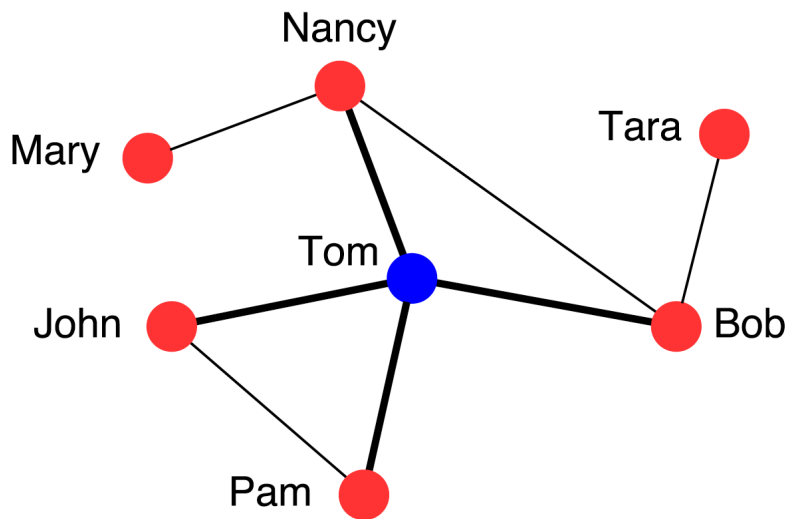
- What is the probability of selecting Tom if we select a random node?
- What is the probability of selecting Tom if we select a random edge and then randomly one of the two nodes attached to it?
- Answer numerically with a simplified fraction



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  $\approx 2.83$  ( $> 2.29$ )

# The friendship paradox

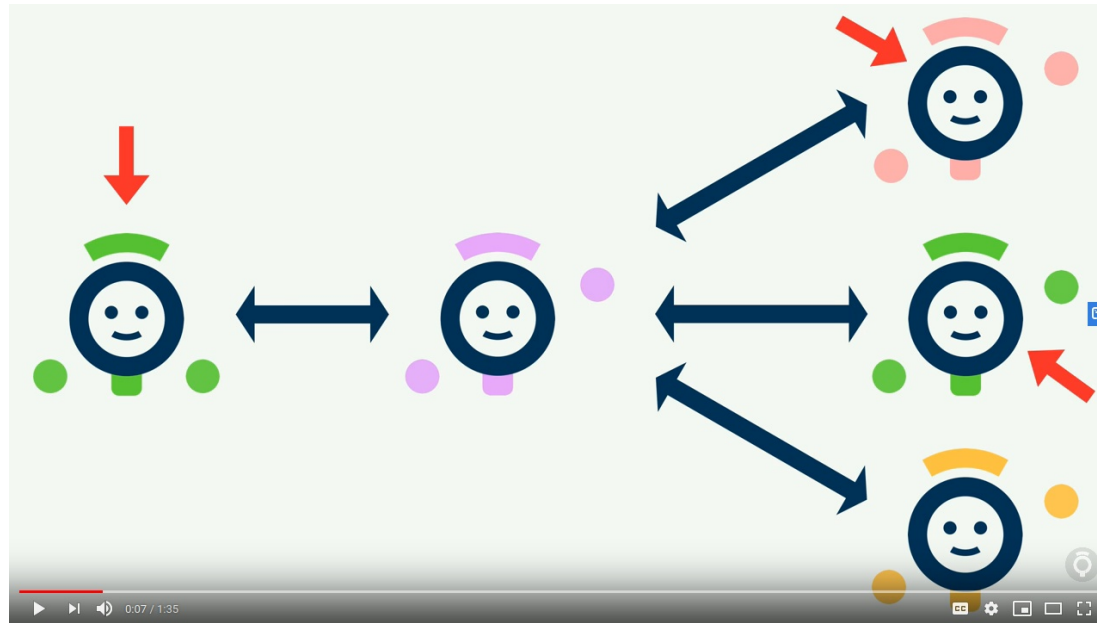
- Take a random person  $x$ ; what is the expected degree of this person?  $\langle k \rangle$
- Take a random person  $x$ , now pick one of  $x$ 's neighbors, let's say  $y$ ; what is the expected degree of  $y$ ?

**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  
<https://nearpod.com/student/>  
Access to be provided during class

# 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  $\langle k_F \rangle > \langle k \rangle$