

Strategic Analysis in Telecommunications Markets

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Non-cooperative game theory

- **Players** motivated by individual **incentives**
- **Interactions** resulting in **payoffs**

Explains:

- **Selfish** but collectively damaging behavior
- How to think **strategically**
- More than one possible **equilibrium** (stable outcome)
- **Rules of the game** matter
- Selfish behavior in **networks**

Explain selfish behavior

Price-setting game

		2	
		<i>high price</i>	<i>low price</i>
1	<i>high price</i>	2 3 2 0	
	<i>low price</i>	0 1 3 1	

Explain selfish behavior

Price-setting game

		2	
		<i>high price</i>	<i>low price</i>
1	<i>high price</i>	2 2 → 3	
	<i>low price</i>	↓ 0 3 ↓ → 1 1	

Explain selfish behavior

Price-setting game

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		<i>high price</i>	<i>low price</i>
1	<i>high price</i>	2 → 3	0
	<i>low price</i>	↓ 3 0	↓ → 1 1

The table illustrates a price-setting game between two players, 1 and 2. Player 1 chooses between high and low prices, and Player 2 chooses between high and low prices. The payoffs are shown in the cells. The cell where both players choose low prices (1, 1) is highlighted with a green border, indicating it is the outcome of selfish behavior.

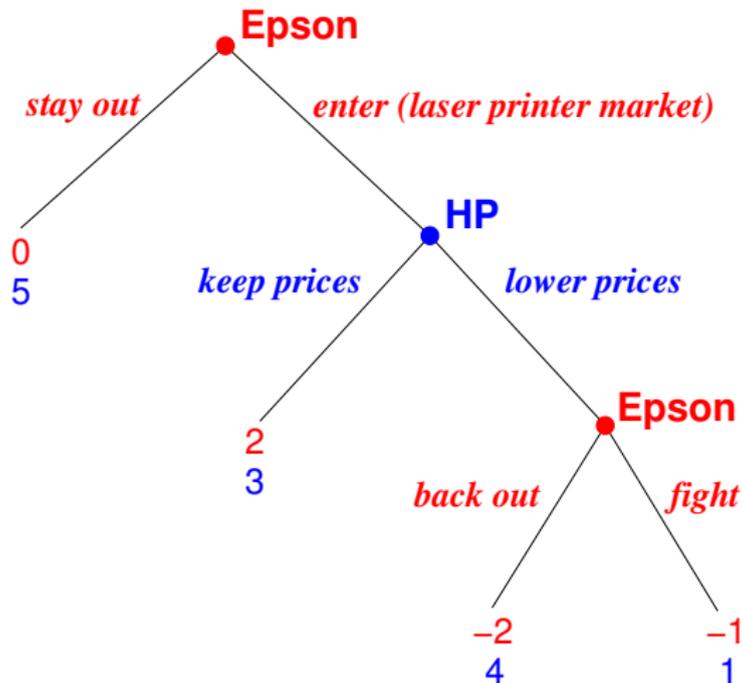
Explain selfish behavior

Fishing game

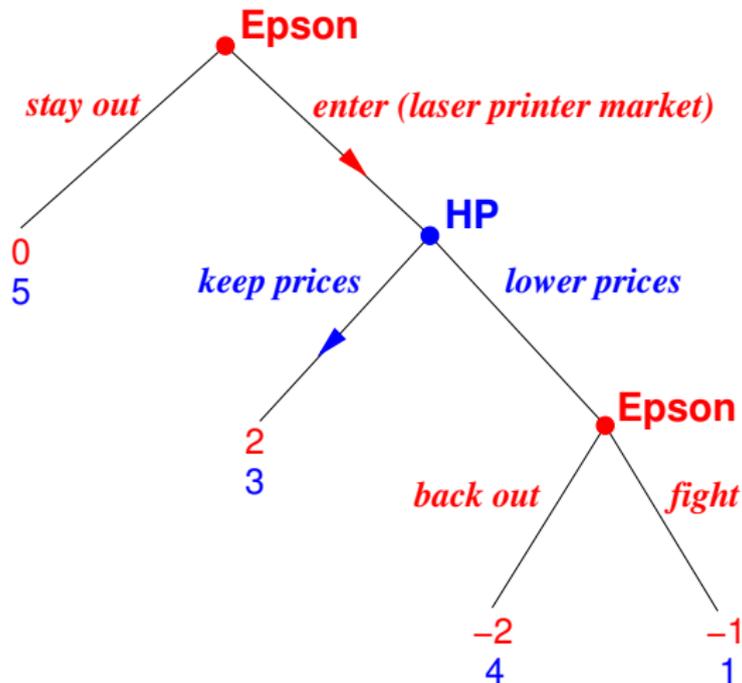
		2	
		<i>sustainable fishing</i>	<i>over-fishing</i>
1	<i>sustainable fishing</i>	2 → 2	→ 3 0
	<i>overfishing</i>	↓ 0 3	↓ → 1 1

price competition positive for consumers, but same game between **fishing nations** detrimental for all!

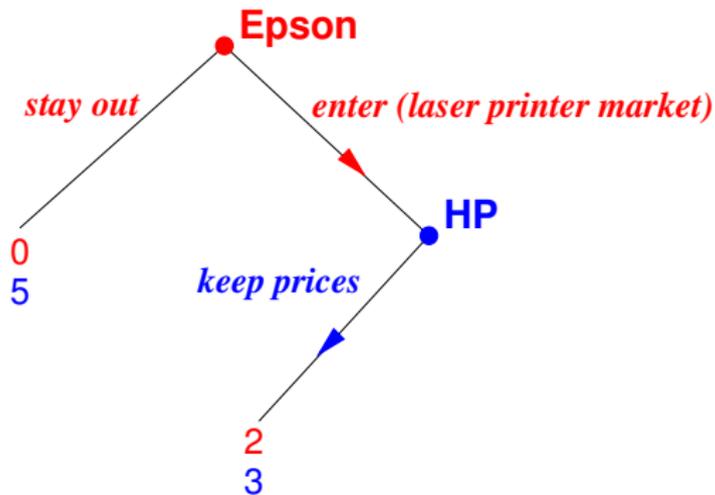
Thinking strategically: **Epson** vs. **HP**



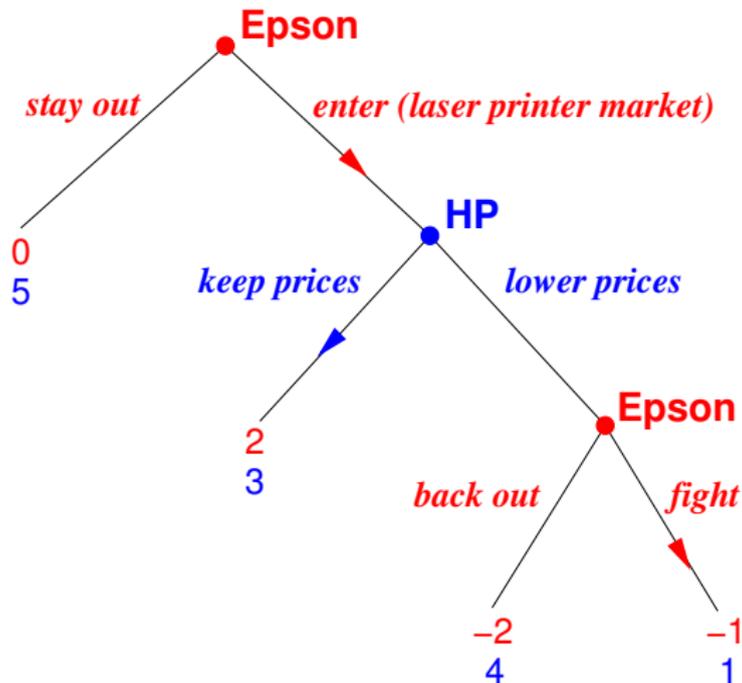
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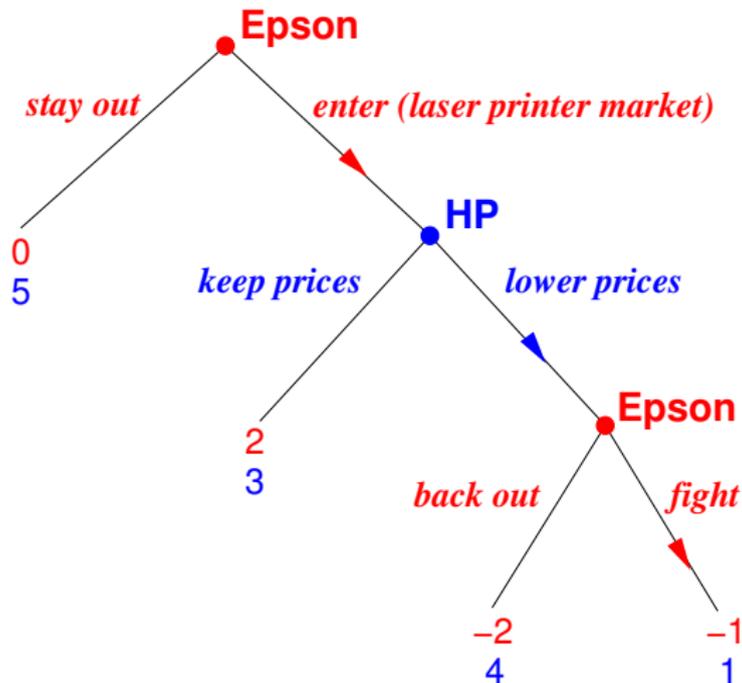
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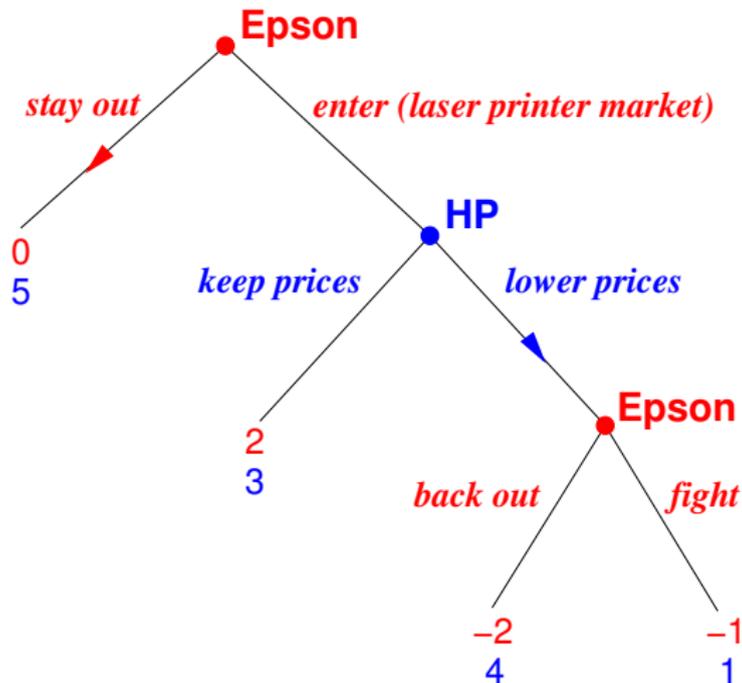
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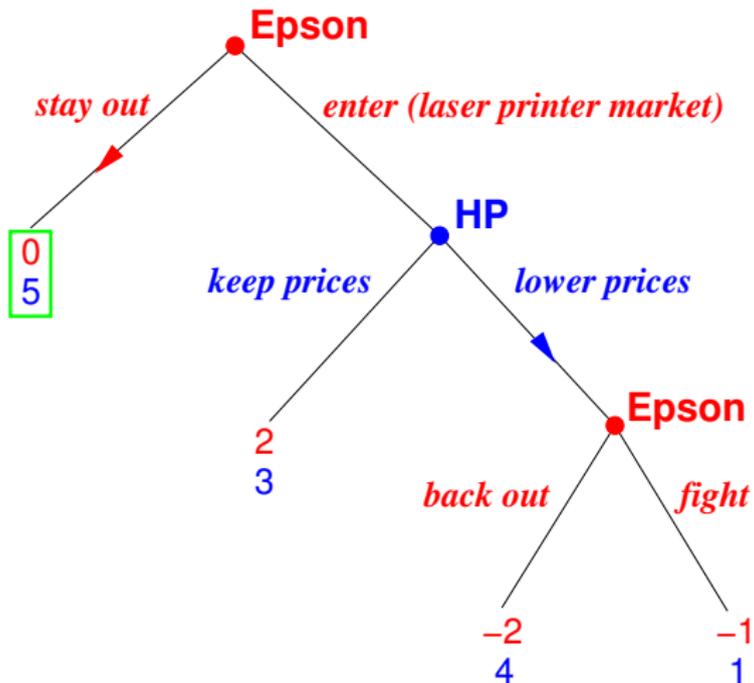
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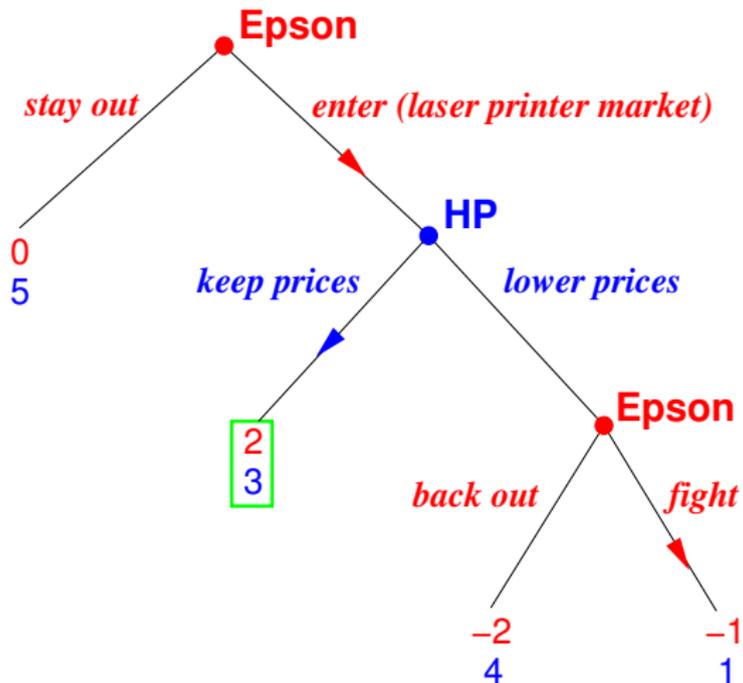
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For example, in the **Epson** vs. **HP** game:

Equilibrium 1: (*stay out*, *lower prices*)

Equilibrium 2: (*enter / fight*, *keep prices*)

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Equilibrium 1: (*stay out*, *lower prices*)

Equilibrium 2: (*enter / fight*, *keep prices*)

not an equilibrium: (*enter / fight*, *lower prices*)

The bandwidth choice game

		2	
		<i>high bandwidth</i>	<i>low bandwidth</i>
1	<i>high bandwidth</i>	5, 5	1, 0
	<i>low bandwidth</i>	0, 1	1, 1

The bandwidth choice game

		2	
		<i>high bandwidth</i>	<i>low bandwidth</i>
1	<i>high bandwidth</i>	5 ← 1	0
	<i>low bandwidth</i>	↑ 1	0 ↓ → 1

A 2x2 payoff matrix for a bandwidth choice game. Player 1 (red) chooses between high and low bandwidth, and Player 2 (blue) chooses between high and low bandwidth. The payoffs are (Player 1, Player 2). In the top-right cell (high, low), there is a blue arrow pointing left from 1 to 5. In the bottom-right cell (low, low), there is a blue arrow pointing right from 1 to 0 and a red arrow pointing down from 0 to 1.

The bandwidth choice game

Which equilibrium?

		2	<i>high band- width</i>	<i>low band- width</i>
1				
<i>high bandwidth</i>			5	1
			5	0
<i>low bandwidth</i>			0	1
			1	1

The bandwidth choice game

Which equilibrium? **Evolved** from starting distribution:

		30 %	70 %	
		<i>high band- width</i>	<i>low band- width</i>	
<i>high bandwidth</i>	1	5	1	1.5
	2	5	0	
<i>low bandwidth</i>	1	0	1	1
	2	1	1	

Diagram description: A 2x2 payoff matrix for a bandwidth choice game. Player 1 chooses between high and low bandwidth, and Player 2 chooses between high and low bandwidth. The starting distribution is 30% high bandwidth and 70% low bandwidth. Payoffs are shown in the cells. Red arrows indicate best responses: Player 1's best response to high bandwidth is high bandwidth (5 > 0), and to low bandwidth is low bandwidth (1 > 0). Player 2's best response to high bandwidth is high bandwidth (1 > 0), and to low bandwidth is low bandwidth (1 > 0). The payoff (5, 1) is circled in red, and the value 1.5 is written to its right. The payoff (1, 1) is circled in red, and the value 1 is written to its right.

The bandwidth choice game

Which equilibrium? **Evolved** from starting distribution:

		50 %	50 %		
		<i>high band- width</i>	<i>low band- width</i>		
<i>high bandwidth</i>	1	5	← 1	2.5	
	2	5	0		
<i>low bandwidth</i>	1	↑ 1	↓ → 1	1	
	2	0	1		

The bandwidth choice game

Which equilibrium? **Evolved** from starting distribution:

		80 %	20 %	
		<i>high band- width</i>	<i>low band- width</i>	
<i>high bandwidth</i>	5	5	← 1	
	5	0		4
<i>low bandwidth</i>	↑ 1	0	↓ → 1	
	1		1	↑ 1

The bandwidth choice game

Which equilibrium? **Evolved** from starting distribution:

		100 %	0 %	
		<i>high band- width</i>	<i>low band- width</i>	
<i>high bandwidth</i>	2	5	1	
	1	5	0	
<i>low bandwidth</i>	2	0	1	
	1	1	1	

Diagram illustrating the bandwidth choice game. The game is a 2x2 matrix with players 1 and 2. Player 1 chooses between high bandwidth and low bandwidth. Player 2 chooses between high bandwidth and low bandwidth. The starting distribution is 100% high bandwidth and 0% low bandwidth. The evolved equilibrium is high bandwidth for both players, with payoffs (5, 5). Red arrows indicate the evolution path: from (1,1) to (1,2) and (2,2) to (2,1), and from (1,2) to (2,1). A green box highlights the (1,1) cell.

Rules of the game matter

The **Quality Game**

		2	
		<i>buy</i>	<i>don't buy</i>
1	<i>high quality</i>	2, 2	1, 0
	<i>low quality</i>	0, 3	1, 1

Rules of the game matter

The **Quality Game**

		2	
		<i>buy</i>	<i>don't buy</i>
1	<i>high quality</i>	2 ← 1	0
	<i>low quality</i>	↓ 0	↓ → 1
		2	3

Rules of the game matter

The **Quality Game**

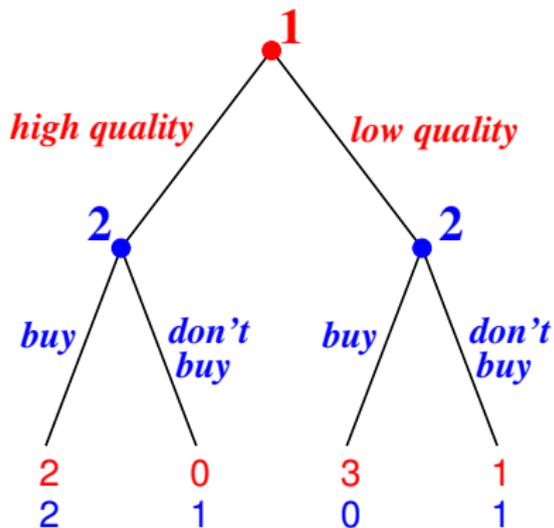
		2	
		<i>buy</i>	<i>don't buy</i>
1	<i>high quality</i>	2 ← 1 2 0	
	<i>low quality</i>	↓ 0 3 1	

The table represents a 2x2 game matrix. The top row is for 'high quality' and the bottom row is for 'low quality'. The left column is for 'buy' and the right column is for 'don't buy'. The top-left cell (high quality, buy) contains a blue '2' and a red '2'. The top-right cell (high quality, don't buy) contains a blue '1' and a red '0'. The bottom-left cell (low quality, buy) contains a blue '0' and a red '3'. The bottom-right cell (low quality, don't buy) contains a blue '1' and a red '1'. A green box highlights the bottom-right cell. Blue arrows point from the blue '1' to the blue '2' in the top-right cell, and from the blue '1' to the blue '0' in the bottom-right cell. Red arrows point from the red '2' to the red '0' in the top-right cell, and from the red '3' to the red '1' in the bottom-right cell.

Rules of the game matter

The **Quality Game** changed to a game with **commitment**

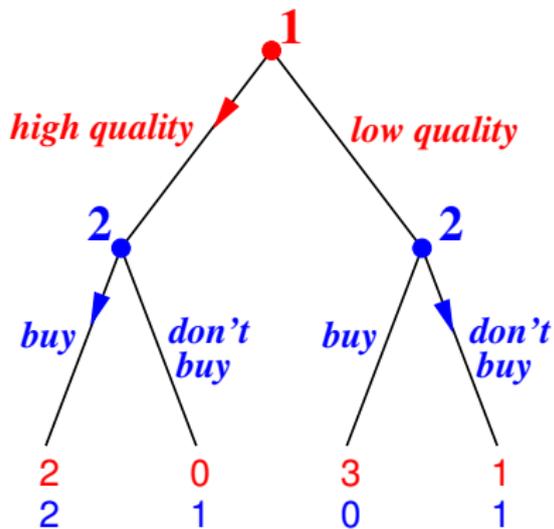
	2	<i>buy</i>	<i>don't buy</i>	
1				
<i>high quality</i>		2	← 1	
	2		0	
<i>low quality</i>		0	→ 1	
	↓ 3		↓ 1	



Rules of the game matter

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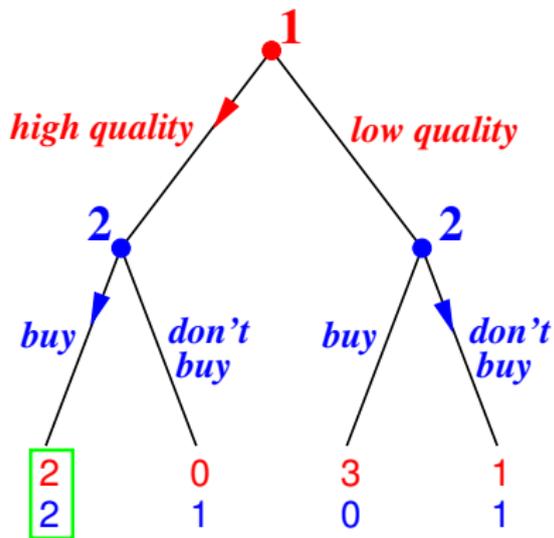
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	↓ 3		↓ 1	



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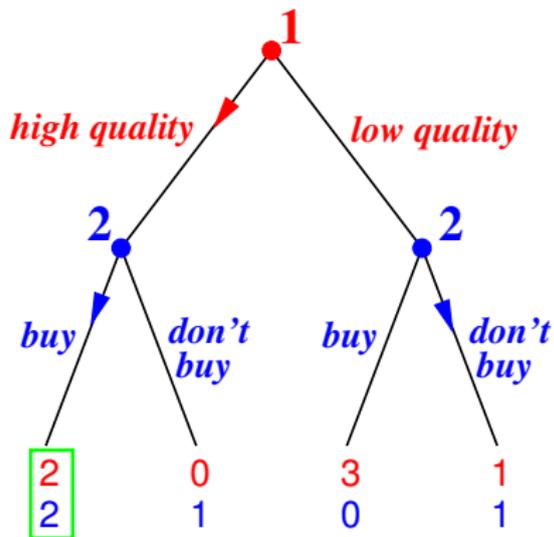
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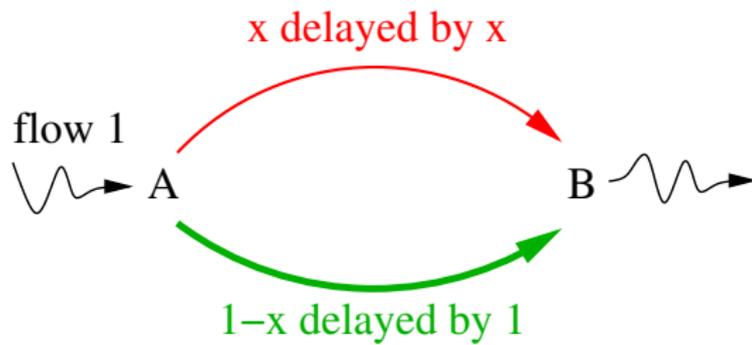
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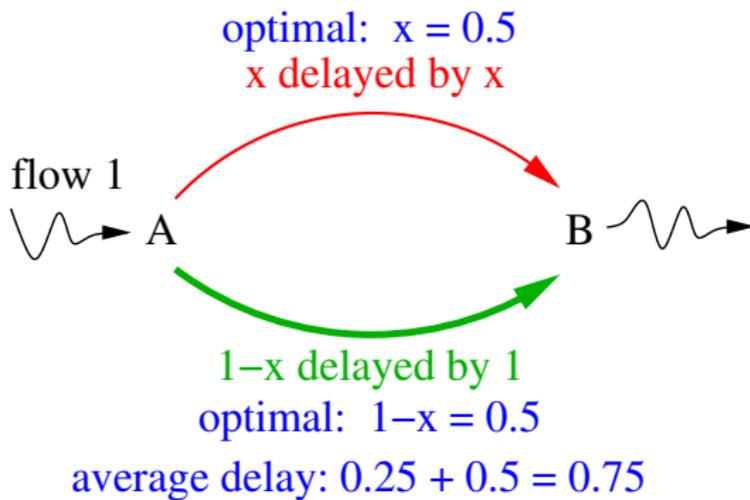


⇒ **Commitment power** can help both players!

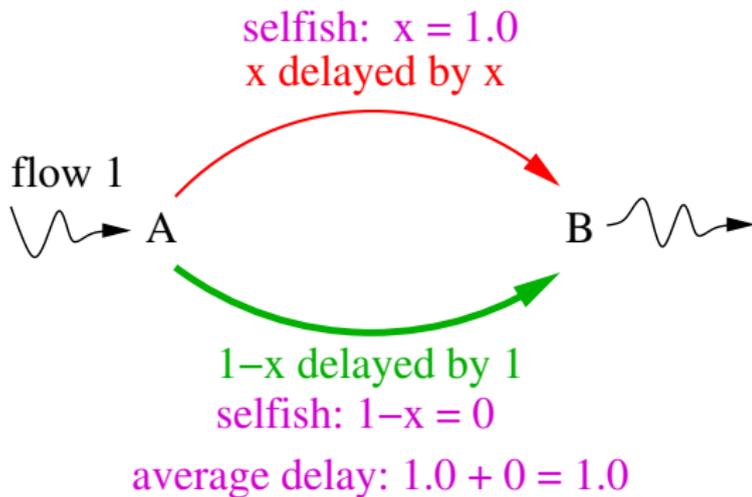
Selfish routing in networks



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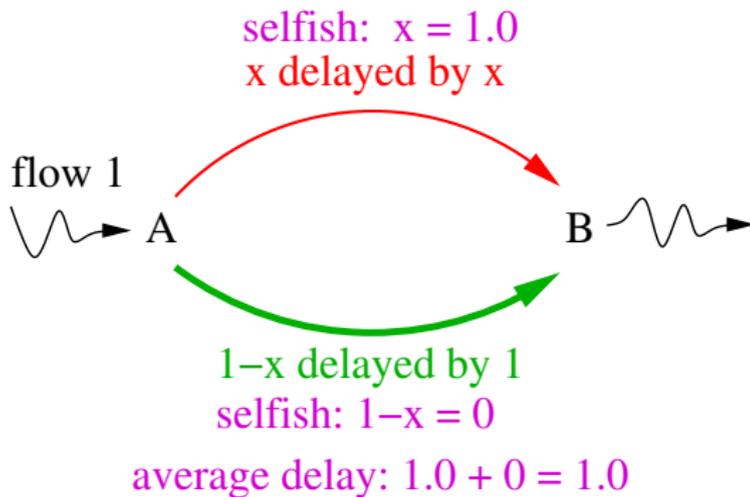


Selfish routing in networks



Selfish routing 33% worse than optimal, centrally planned routing

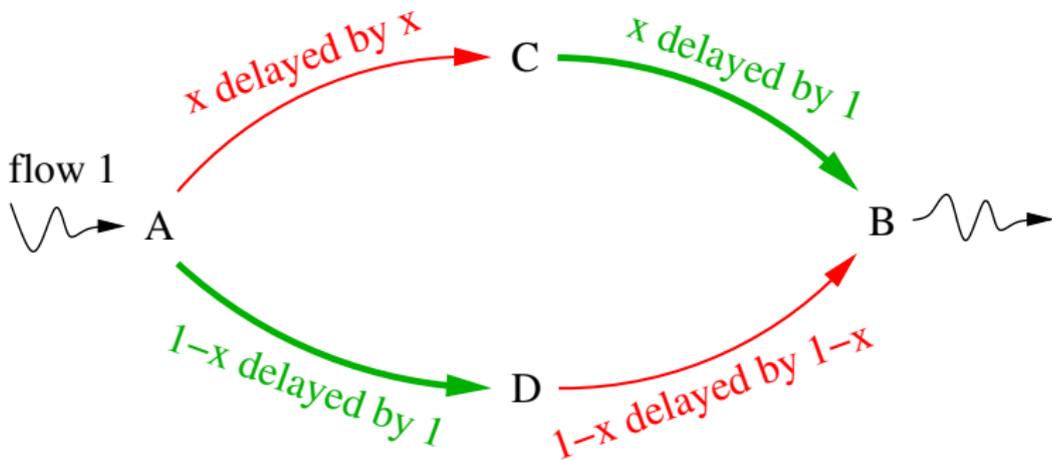
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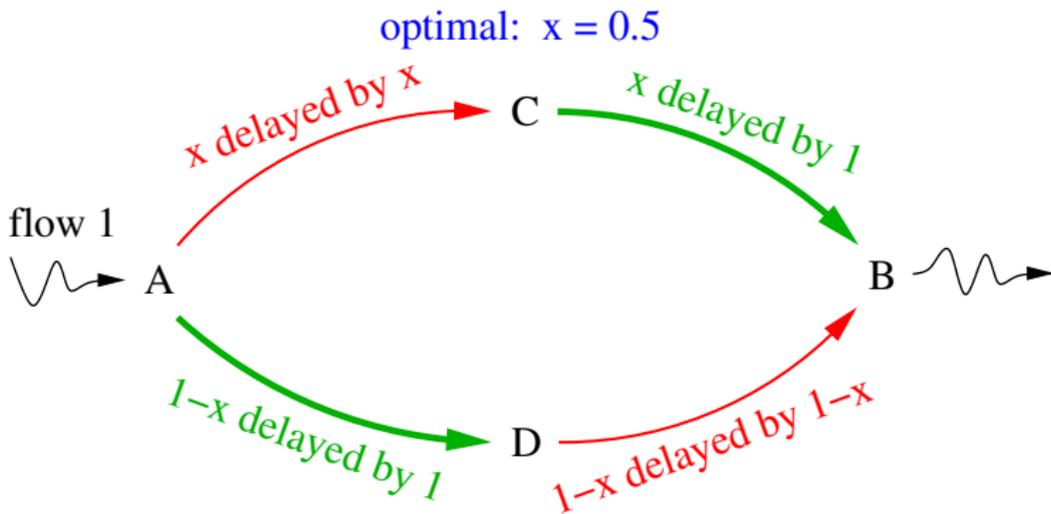
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(33% longer delay is worst possible if delay functions are linear, e.g. flow x delayed by x)

Selfish routing can be optimal

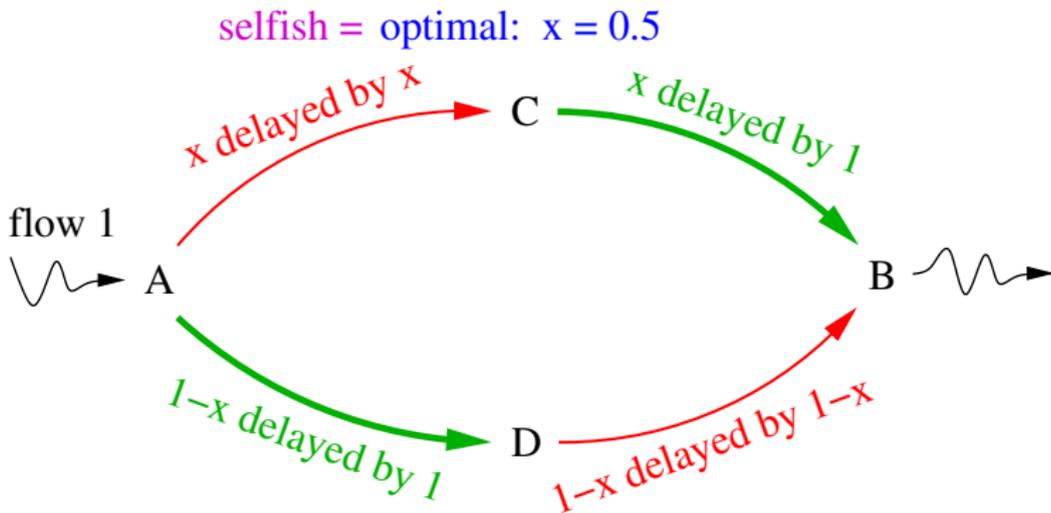


Selfish routing can be optimal



optimal: $1-x = 0.5$
optimal average delay: $0.75 + 0.75 = 1.5$

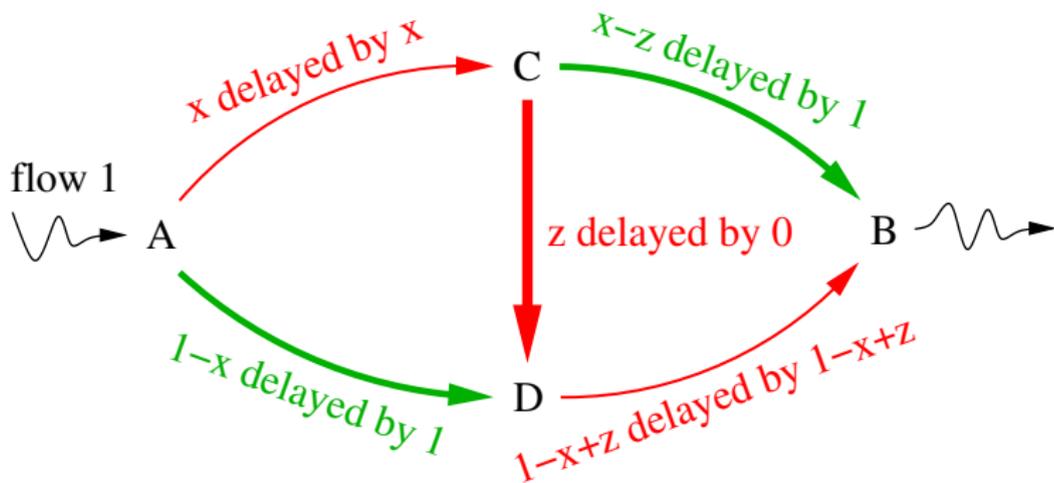
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selfish = optimal: $1-x = 0.5$

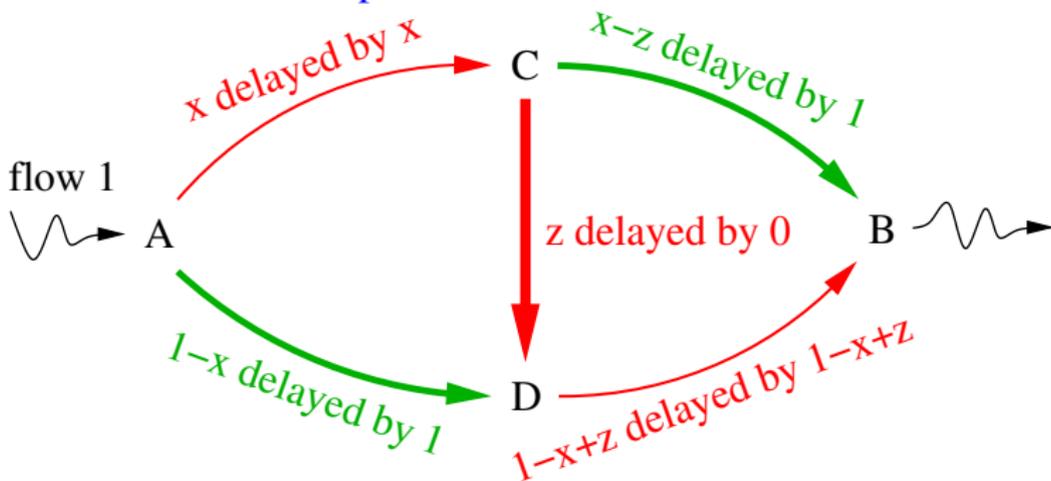
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Add a shortcut



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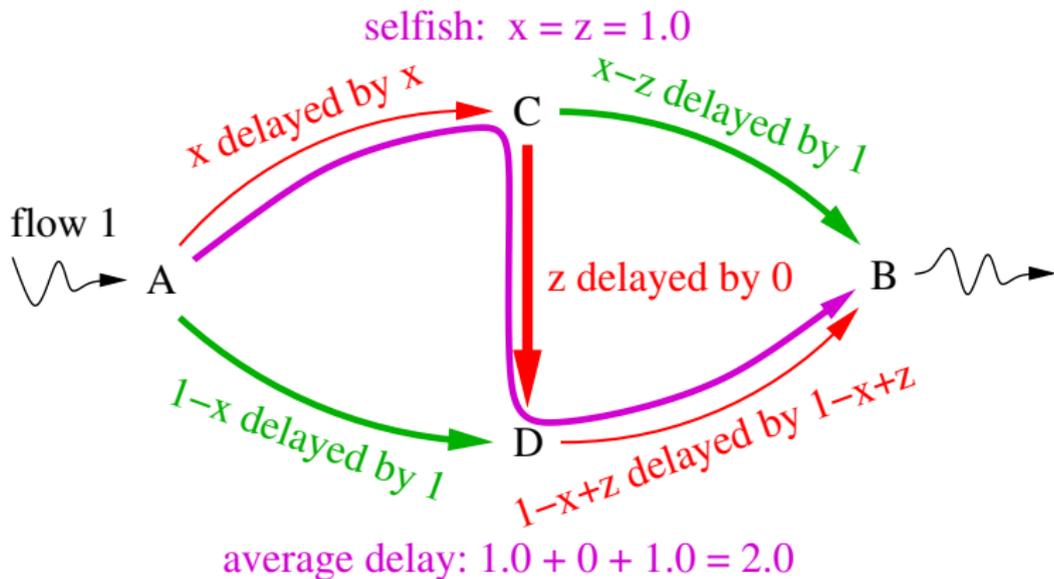
optimal: $x = 0.5, z = 0$



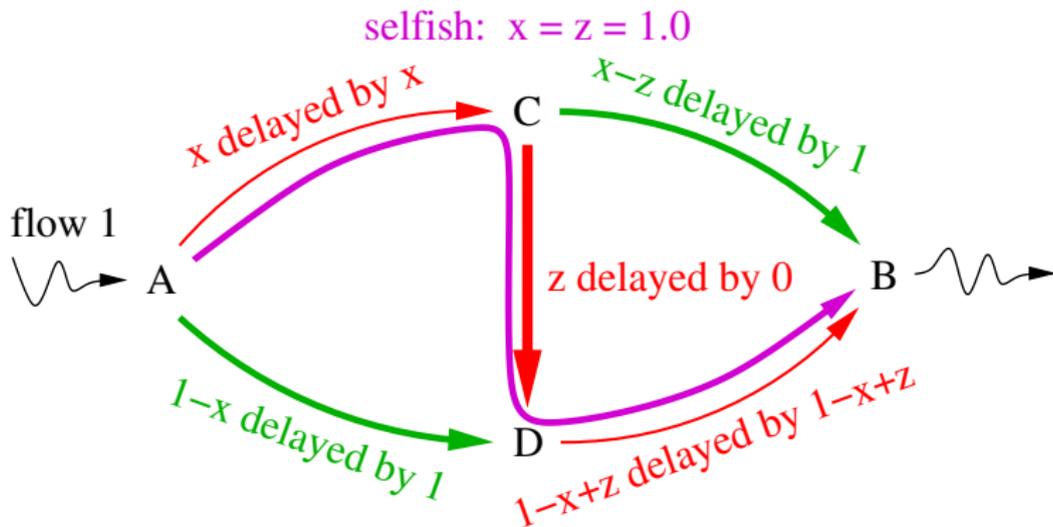
optimal: $1-x = 0.5$

optimal average delay: $0.75 + 0.75 = 1.5$

Add a shortcut



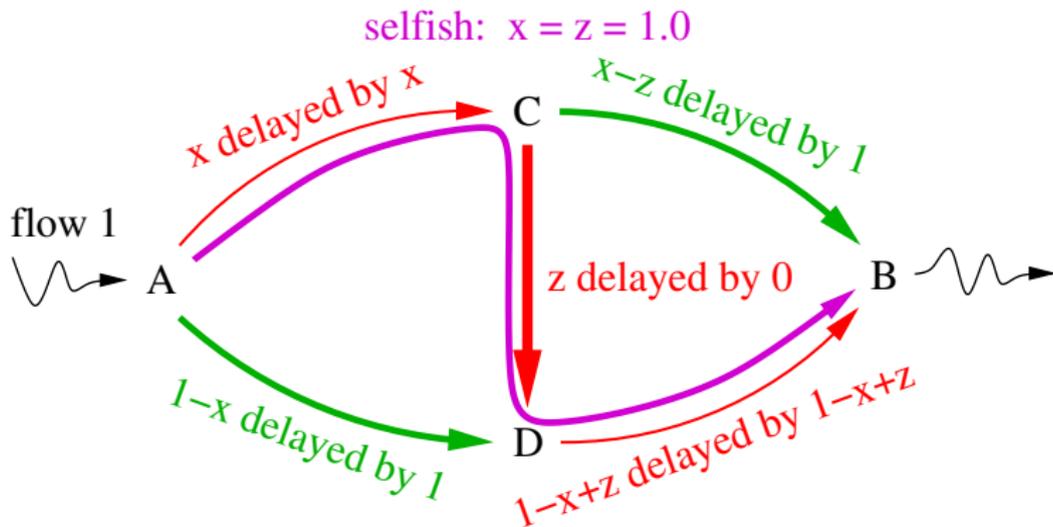
Add a shortcut



average delay: $1.0 + 0 + 1.0 = 2.0$

optimal average delay: $0.75 + 0.75 = 1.5$

Braess's paradox



average delay: $1.0 + 0 + 1.0 = 2.0$

optimal average delay: $0.75 + 0.75 = 1.5$

Increasing network capacity can **worsen** equilibrium congestion!

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- central concept: **equilibrium** (not always unique)
- **explain:** **selfish behavior** in competition, networks and routing
- many more applications: design of auctions, optimal bidding,
...