When is “Altruism” good in distributed decision-making?

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IEEE Computer Society – Pikes Peak Chapter
4/13/2023

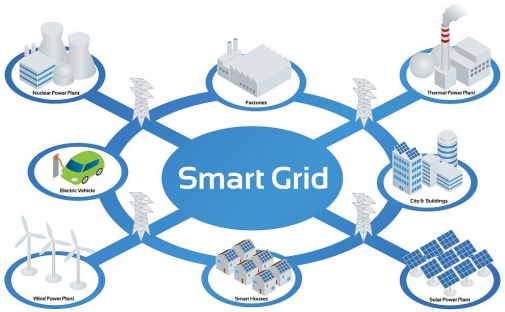
Engineered System

1001101
0010011

Performance

Social System

?



Engineered System

1001101
0010011

- Large, complex
- High uncertainty
- Optimizees are optimizers

Social System

?

Engineered System

1001101
0010011

Design This

- Large, complex
- High uncertainty
- People aren't machines

Social System

When this is given

?

What is Algorithmic Game Theory?

?

What is Algorithmic **Game Theory?**

Game Theory: The mathematics of strategic interaction

When strategic decision-makers interact, what happens?

1930s-1950s: Mathematics (John von Neumann, John Nash)

?

Nash Nash?

What is Algorithmic **Game Theory?**

Game Theory: The mathematics of strategic interaction

When strategic decision-makers interact, what happens?

1930s-1950s: Mathematics (John von Neumann, John Nash)

1960s-1990s: Economics

Descriptive

?

2000s-present: Engineering and Computer Science

Prescriptive

Christos Papadimitriou: “Algorithms, Games, and The Internet” (STOC 2001)

Decision Science and Control Lab Projects

Resilient Multiagent Coordination

Adaptation policies
+
uncertain communication

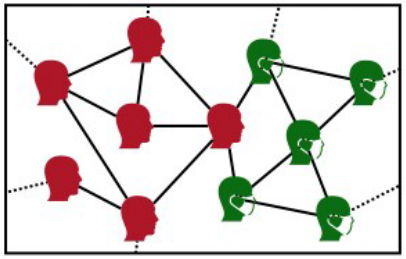
Air Force Office of Scientific Research
FA9550-23-1-0171

Smart Infrastructure

Design incentives
constraints
+
uncertainty

National Science Foundation
ECCS-2013779

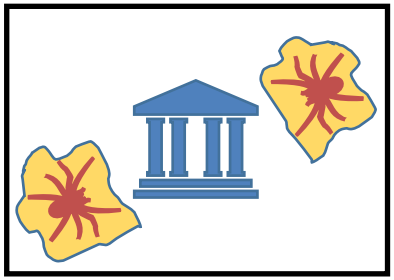
Disease ←→ Behavior



Socially-aware
Pandemic
mitigation

National Science Foundation
DEB-2032465

Strategy-Aware Security



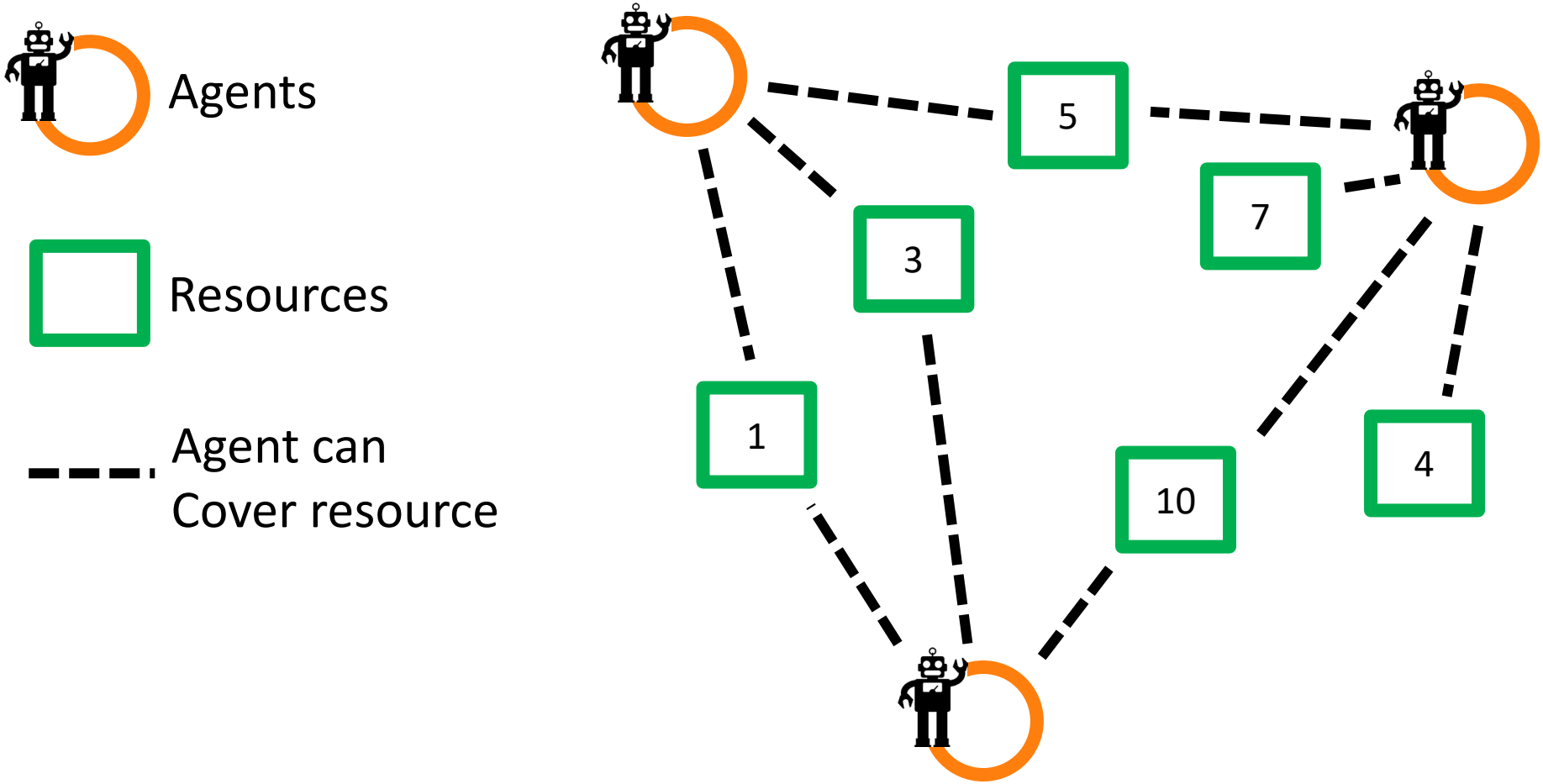
Adversary strategy
+
security?

National Security Agency
H98230-21-1-0155

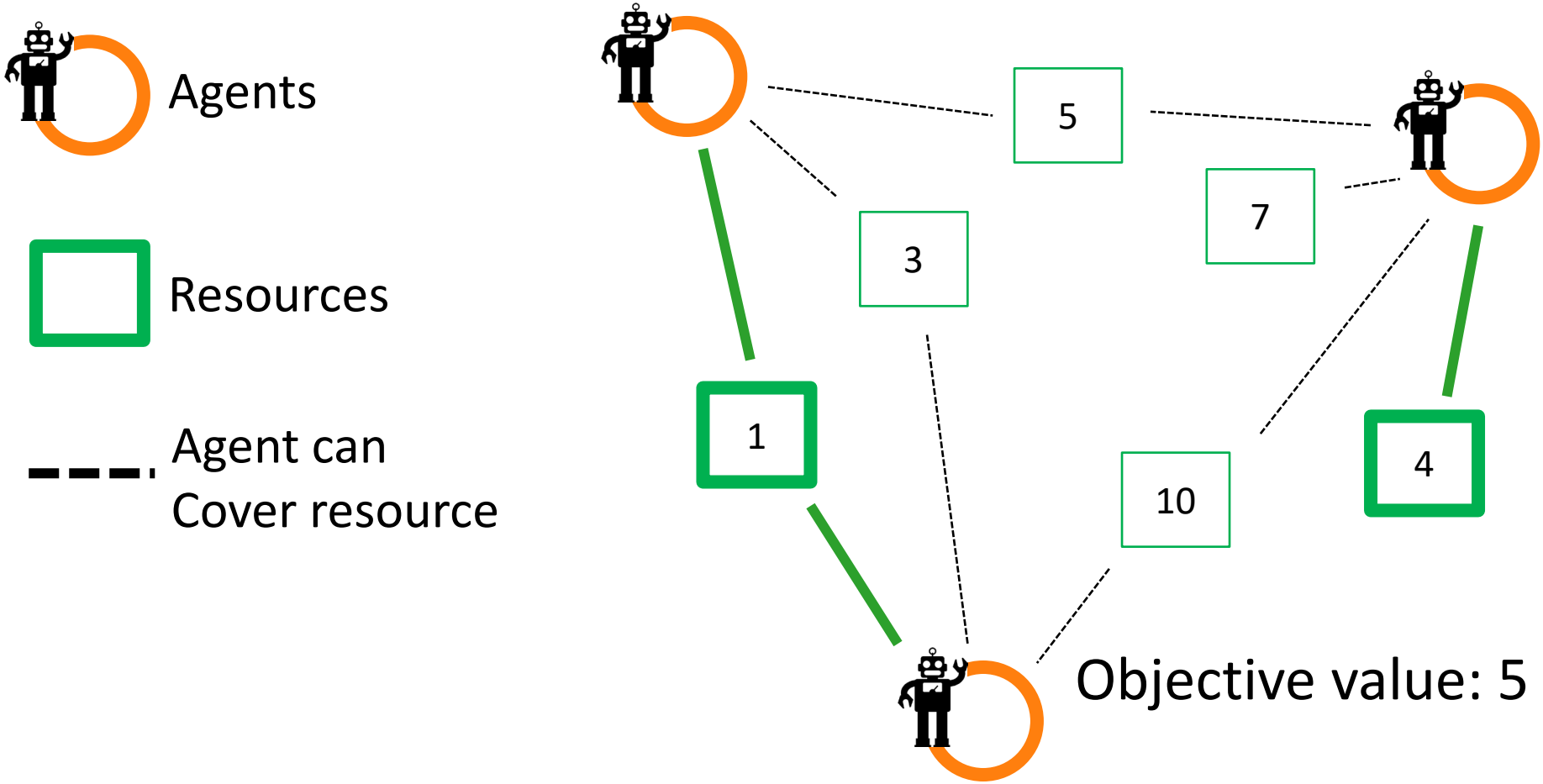
How should interacting autonomous agents behave in **compromised** environments?

blind?

How should interacting autonomous agents behave in **compromised** environments?



Agents' Goal: maximize value of covered resources
(each can only cover 1 box)



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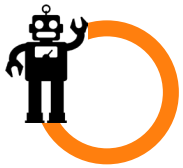
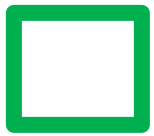
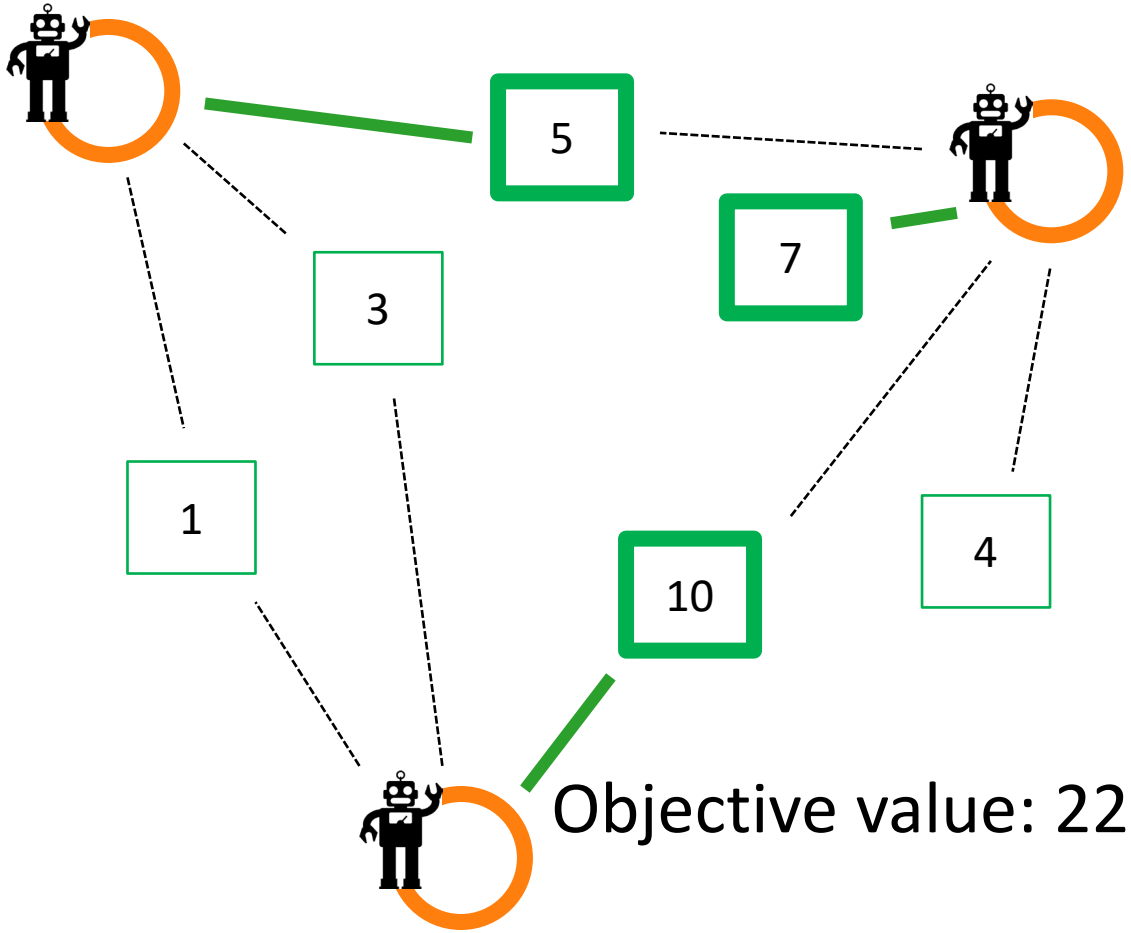


Agents



Resources

Agent can
Cover resource



Objective value: 22

Agents' Goal: maximize value of covered resources
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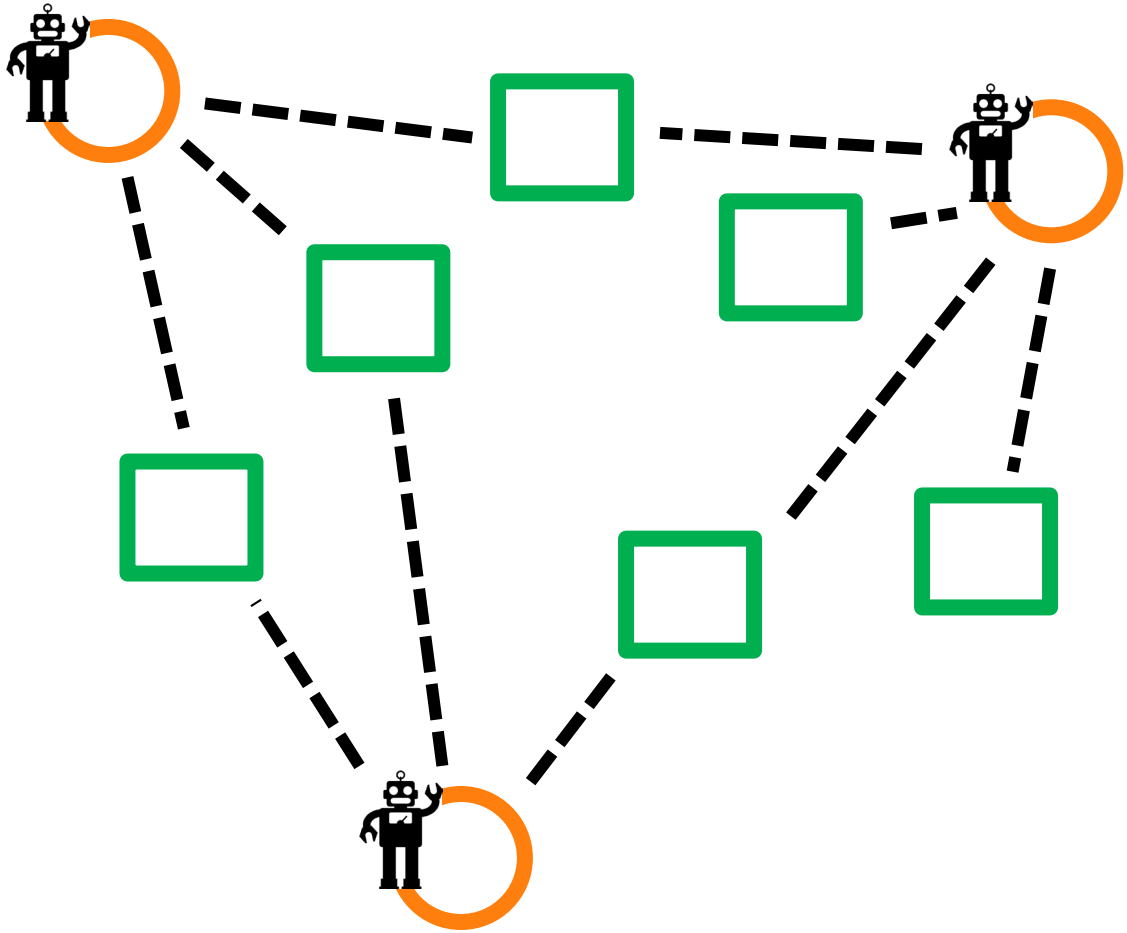
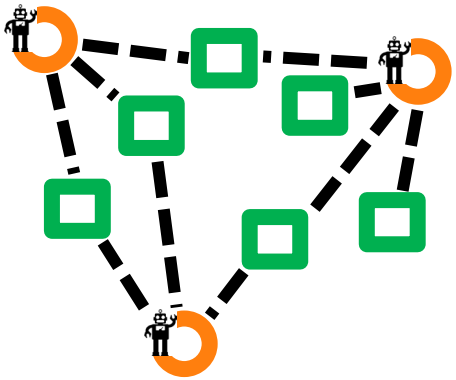


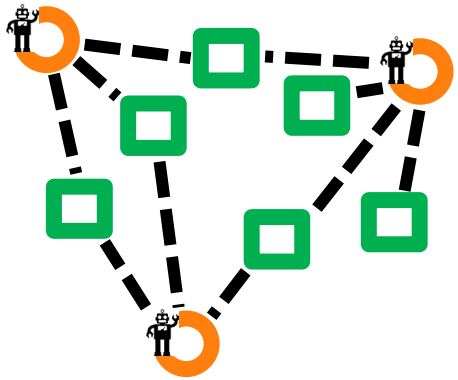
What is the engineer's challenge?



Centralized Paradigm: Given the whole problem, what's the solution?

Problem: what if communicating whole problem isn't possible?

What is the engineer's challenge?



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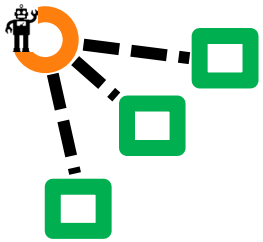
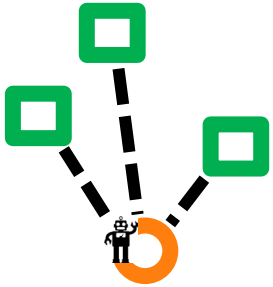
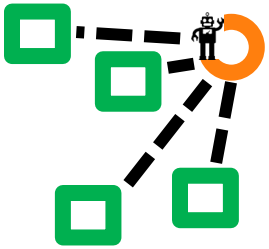
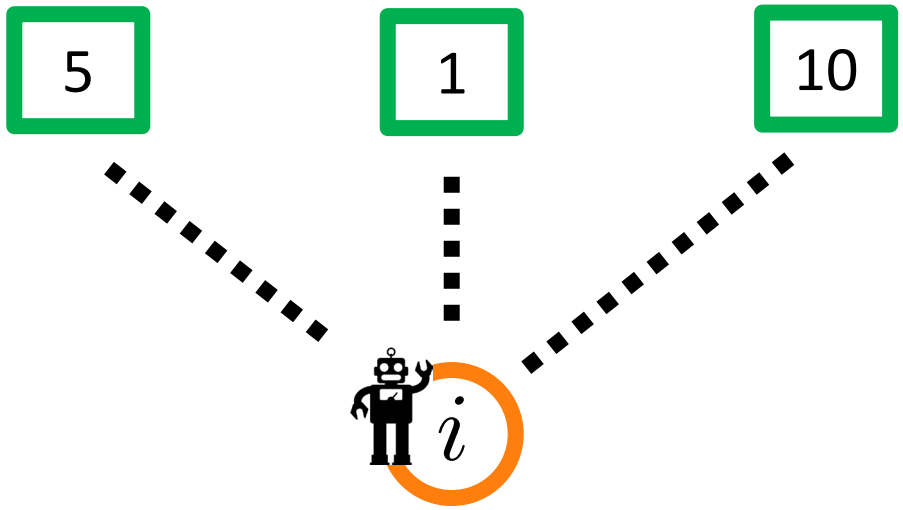






Decentralized Paradigm: What should individual agents do, given what they can see?

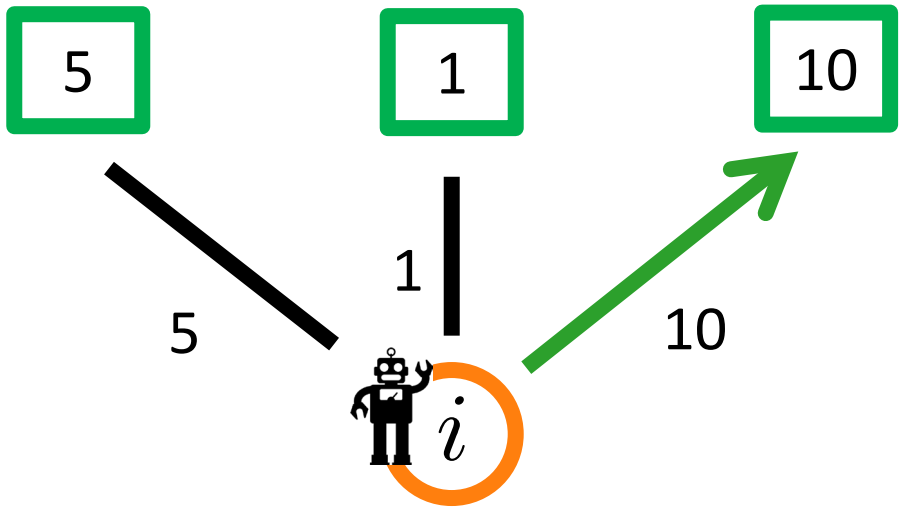
What is the engineer's challenge?



How should agent *i* value the resources it can cover?

Altruism: Value my choice at its contribution to system

"Marginal Contribution"



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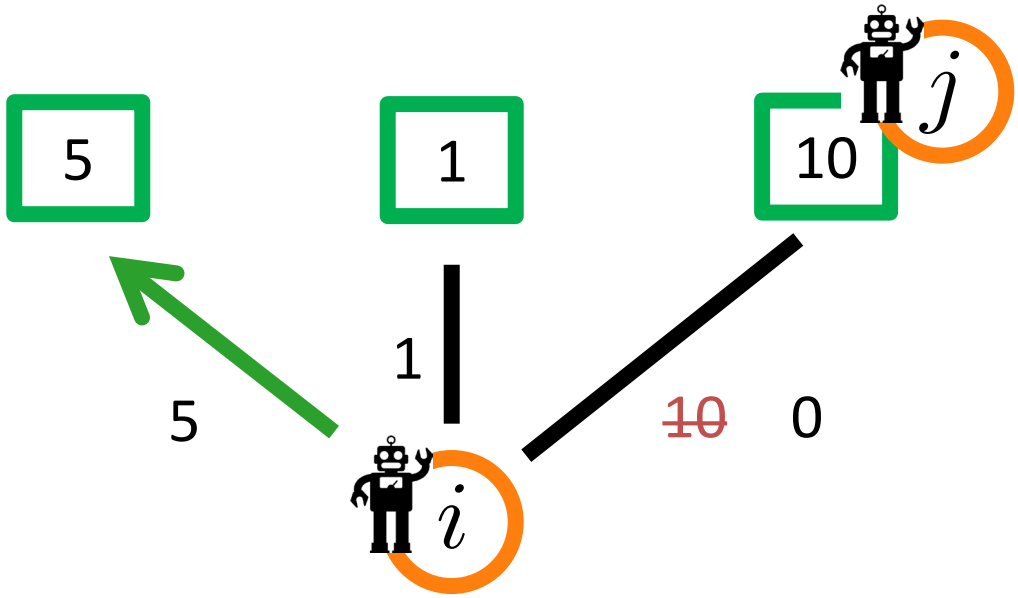

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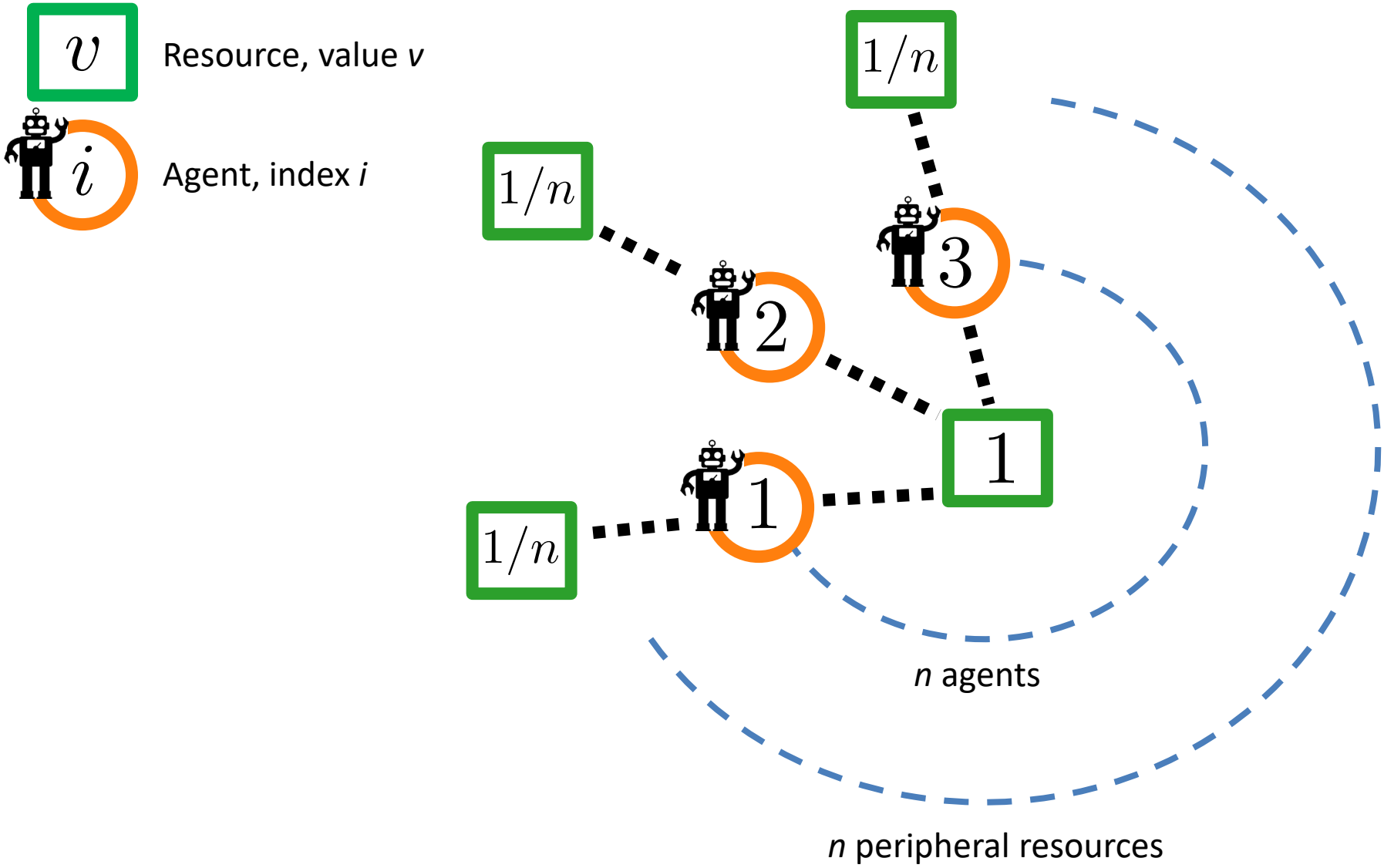
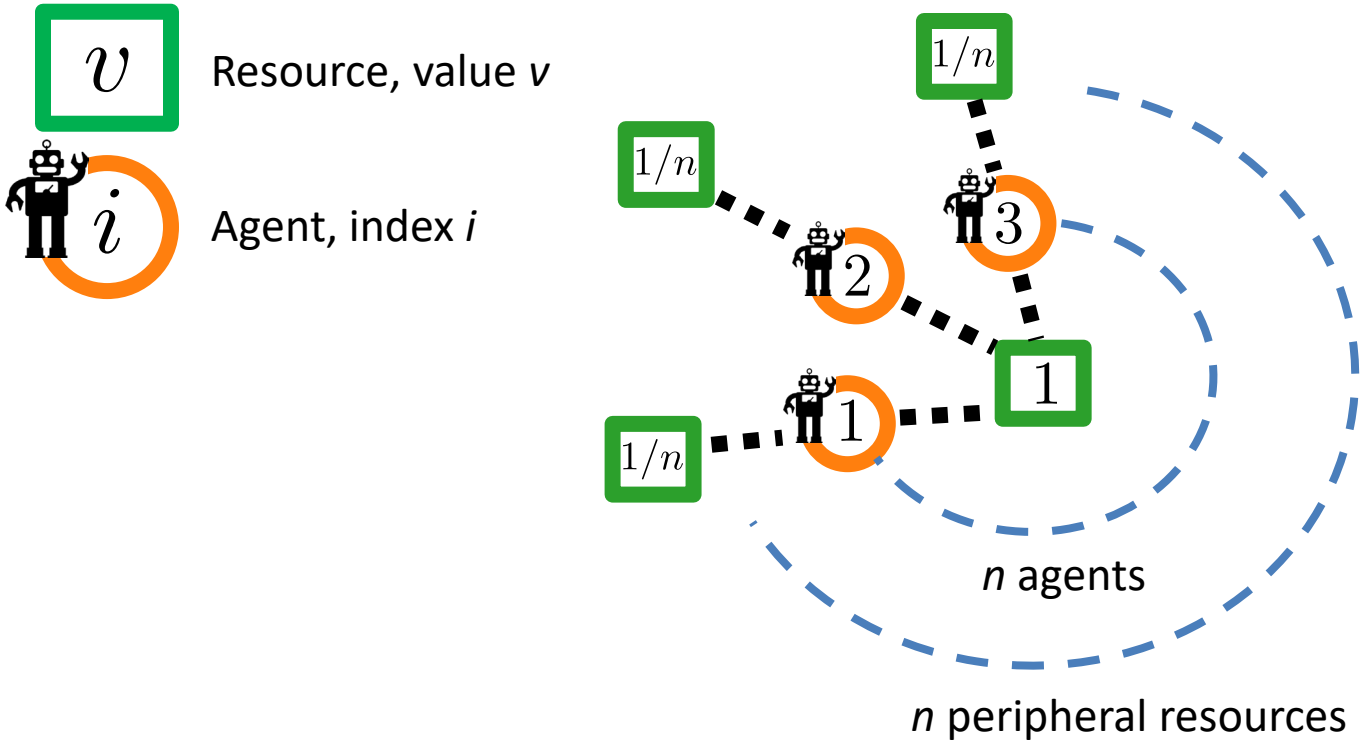
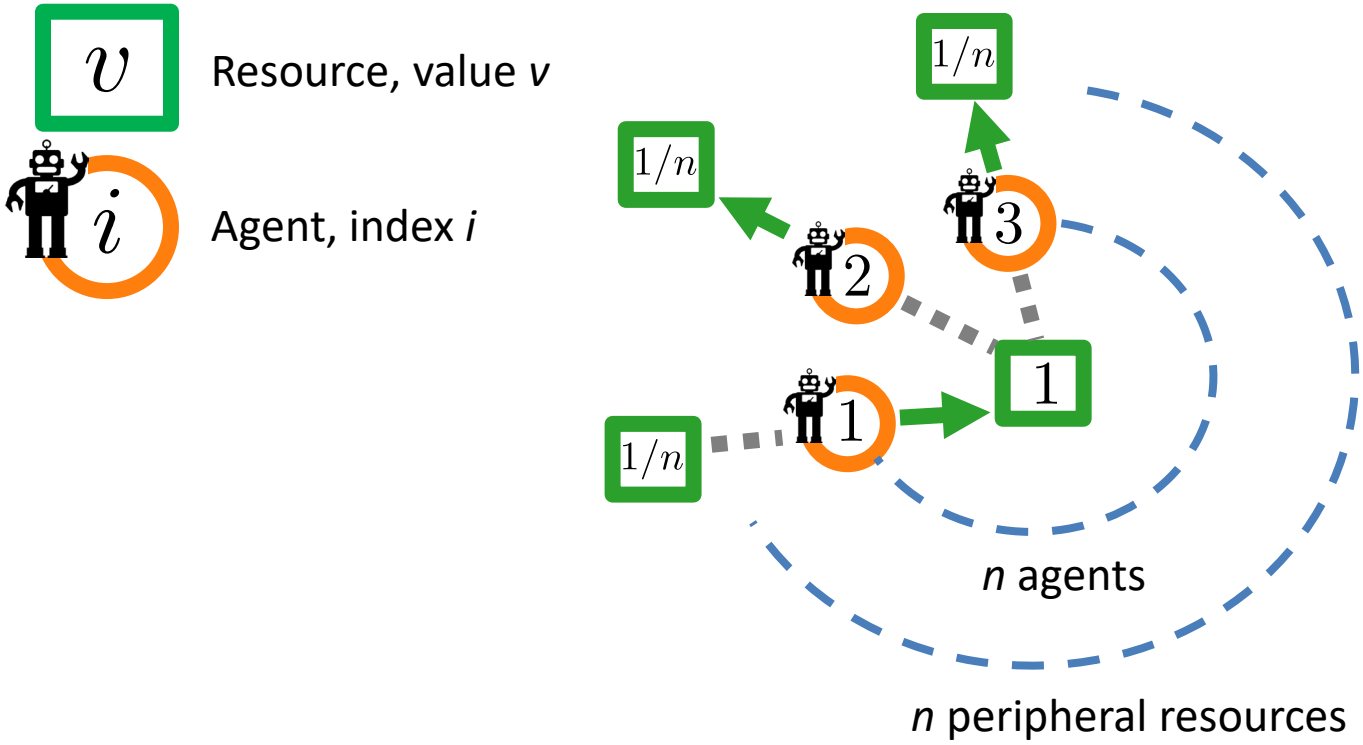

v
Resource, value *v*
i
Agent, index *i*
$1/n$
$1/n$
$1/n$
3
2
1
1
n agents
n peripheral resources

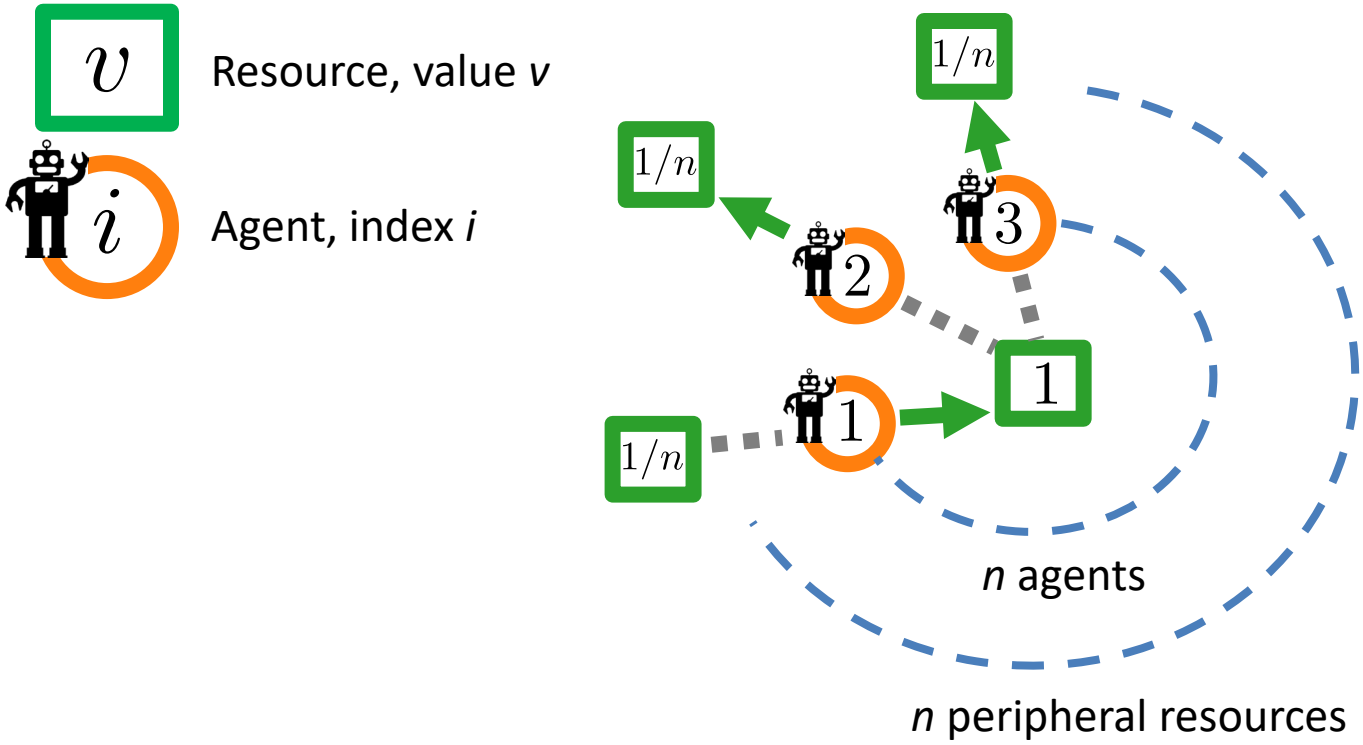


Q: What is good here?



Q: What is good here?

A: One agent in center, all others on periphery



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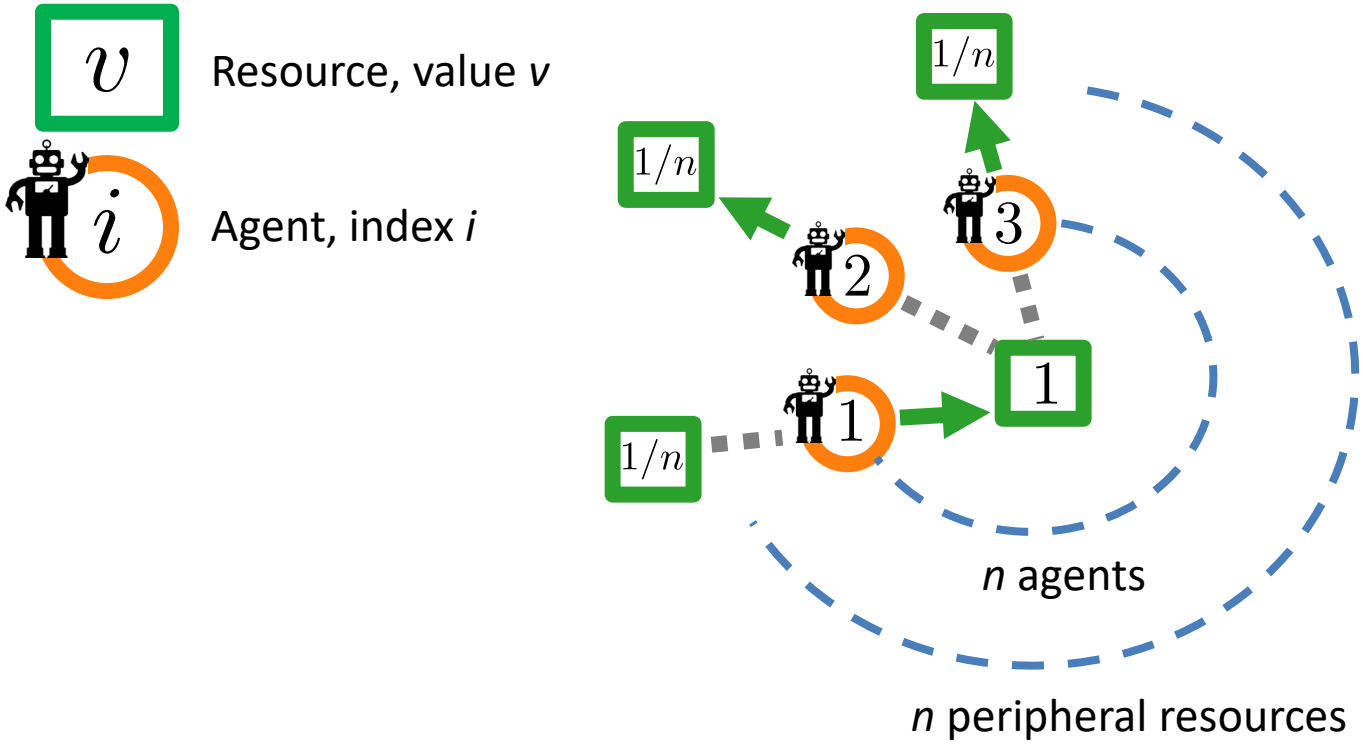
Q: Does altruism get us there?



Q: What is good here?

A: One agent in center, all others on periphery

~~Q: Does altruism get us there?~~

Q: Are the Nash Equilibria with altruism optimal?

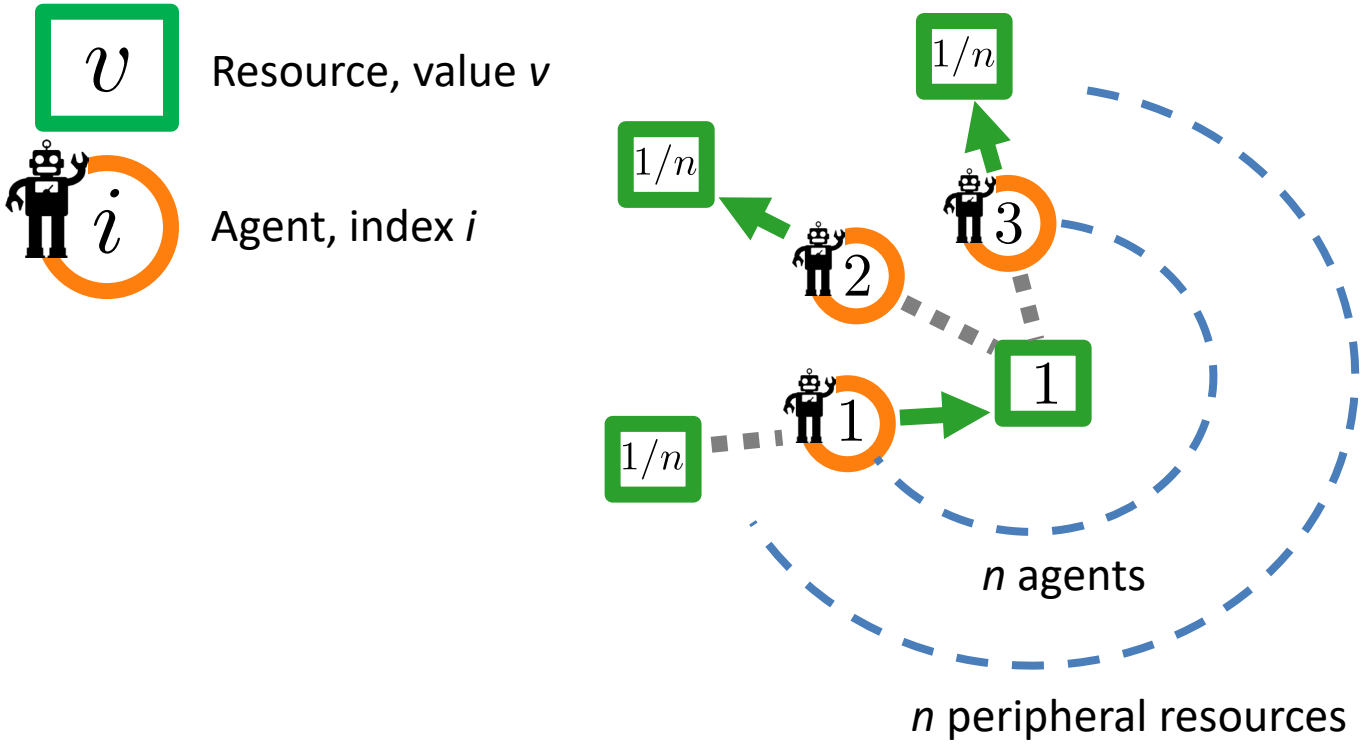
Nash Equilibrium:

An outcome where *no agent* can change and be *strictly better off.*

Q: Wha

~~Q: Does altruism get us there?~~

Q: Are the Nash Equilibria with altruism optimal?



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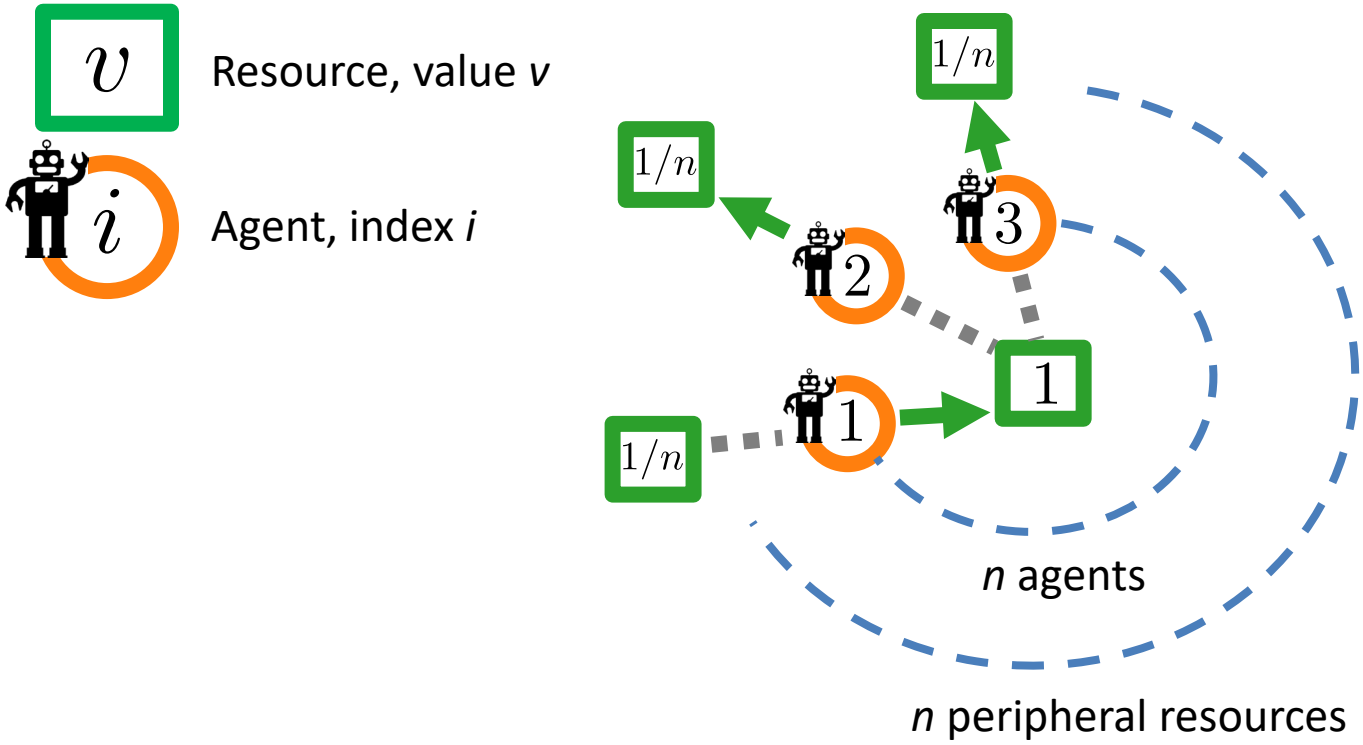
Q: Does altruism get us there (altruistic NE optimal)?



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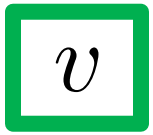
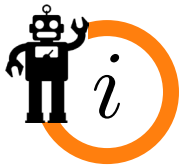
A: One agent in center, all others on periphery

Q: Does altruism get us there (altruistic NE optimal)?

A: Yes, robustly! → Every Nash Equilibrium is optimal



Resource, value *v*

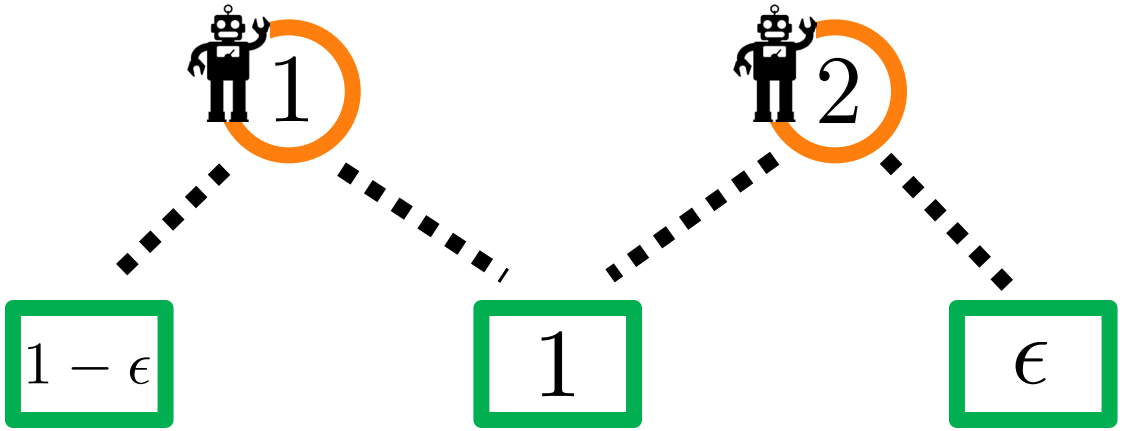


Agent, index *i*

Q: Does altruism get us there?

A: Yes, robustly!

Universally?



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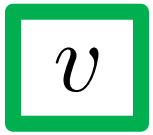

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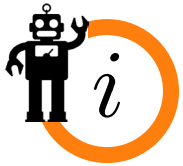

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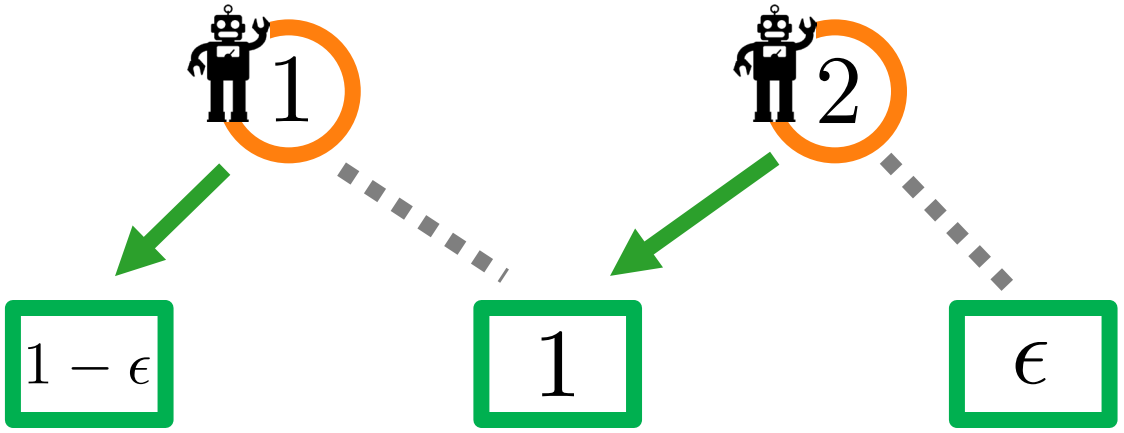

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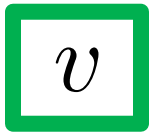
Q: Does altruism get us there?

A: It can…



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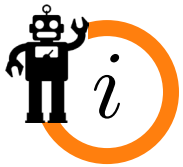

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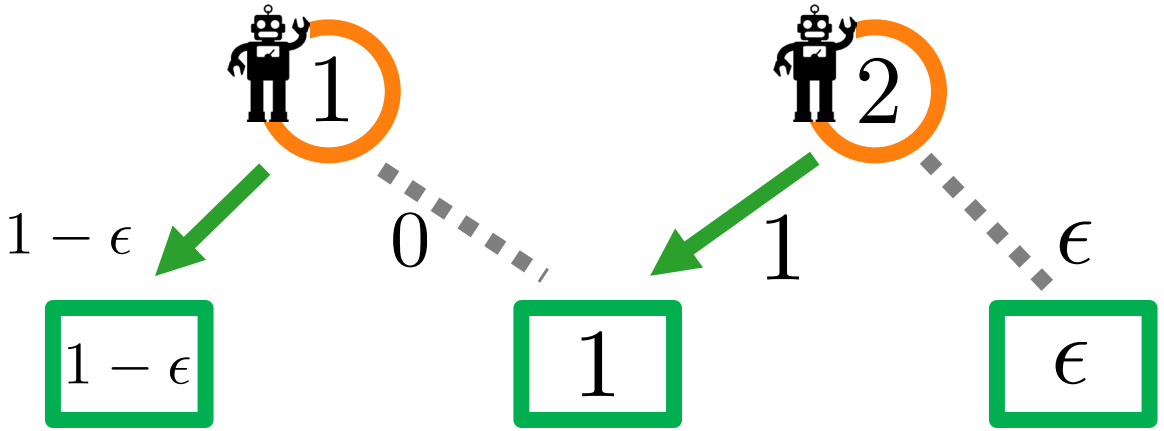

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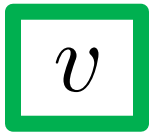

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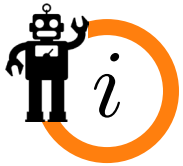

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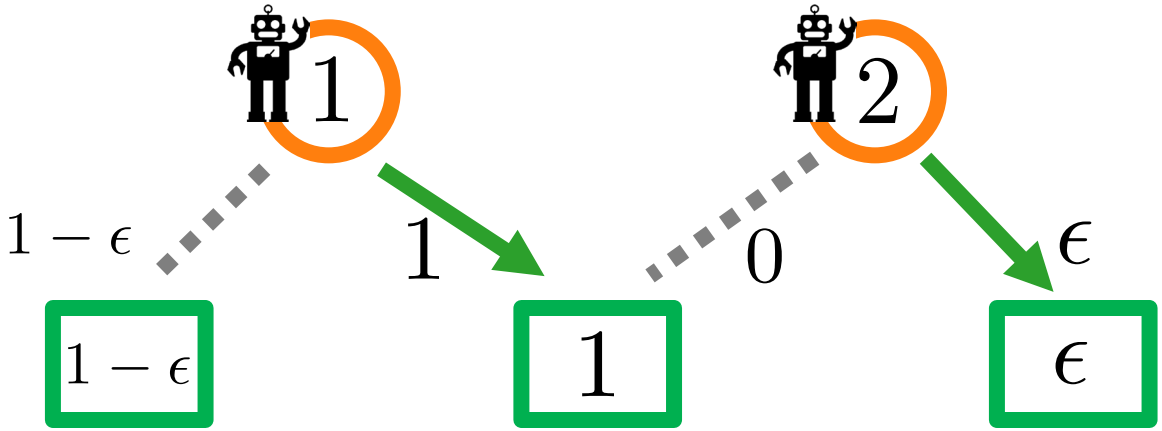

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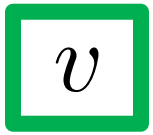

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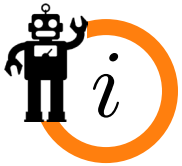


A

Fact: in this class of games,

Altruism

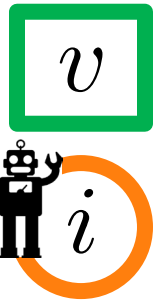
All Nash Equilibria
within 50% of optimal

Price of Anarchy = $\max \dfrac{W(\mathrm{NE})}{W(\mathrm{Optimal})}$

Q: Wha

Q: Does a

A: It can… But it need not.



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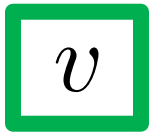
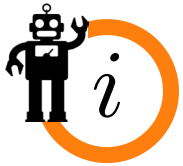


Resource, value *v*



Agent, index *i*

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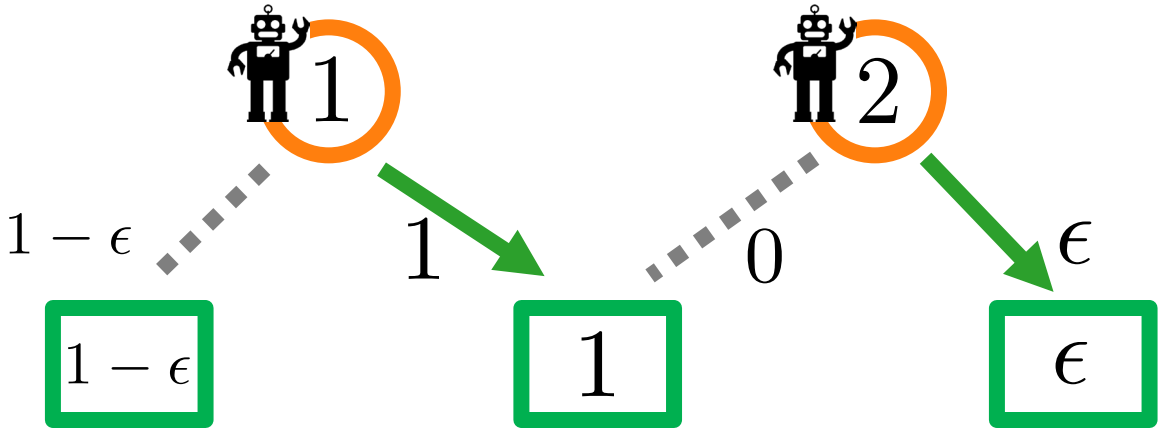

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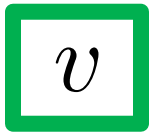

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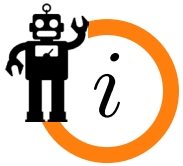

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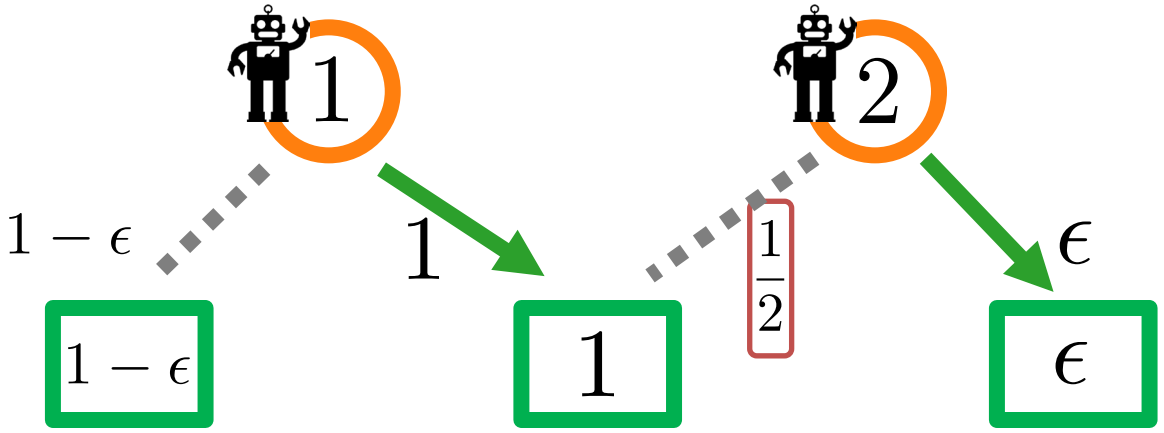
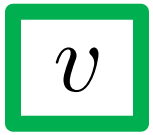
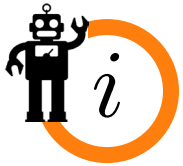


Q: What is better here?

A: “Equal Share” (encourage redundancy)



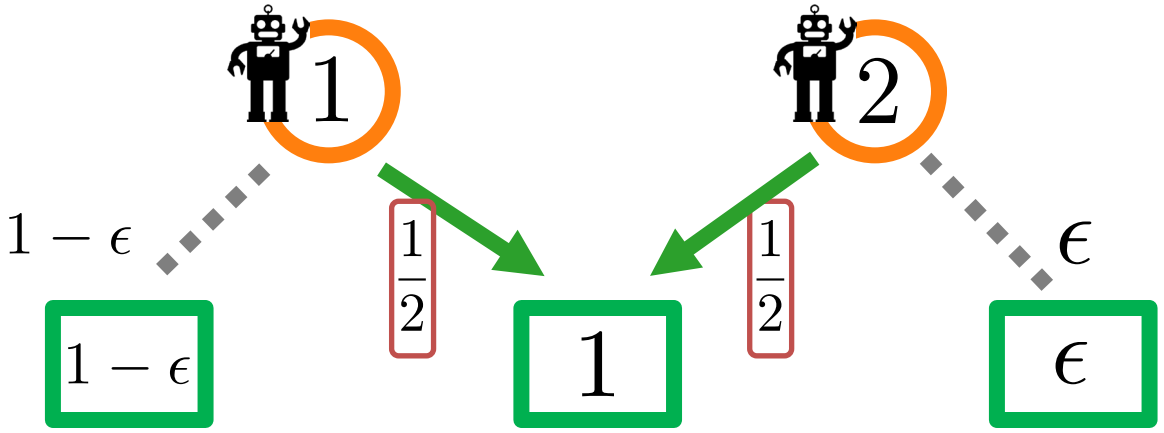
Resource, value *v*



Agent, index *i*

Fact: in this class of games,

$$\mathrm{PoA}(\text{altruism}) = \frac{1}{2}$$



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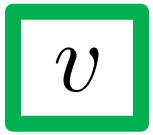
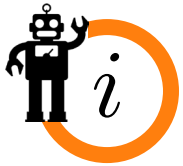


Resource, value *v*



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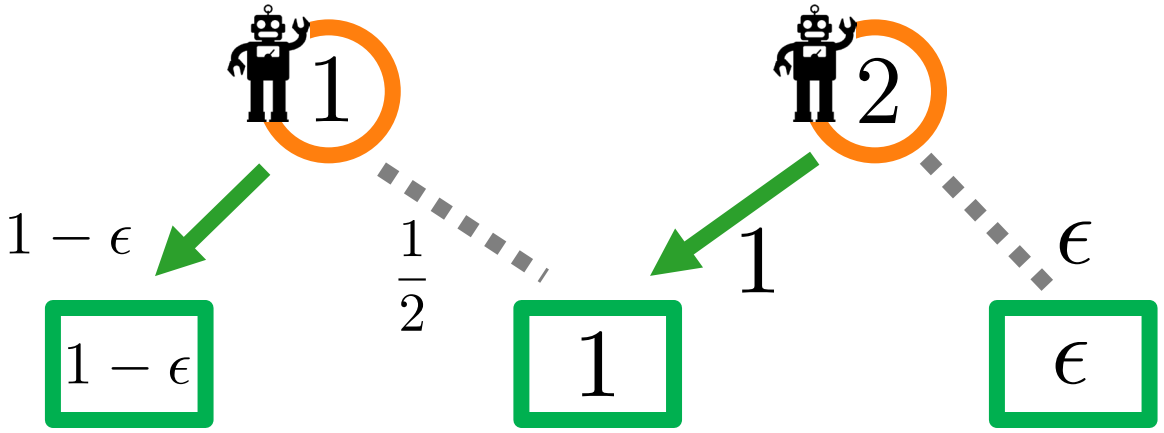

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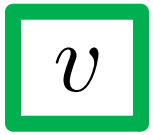
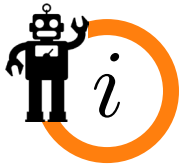


Resource, value *v*



Agent, index *i*

Fact: in this class of games,

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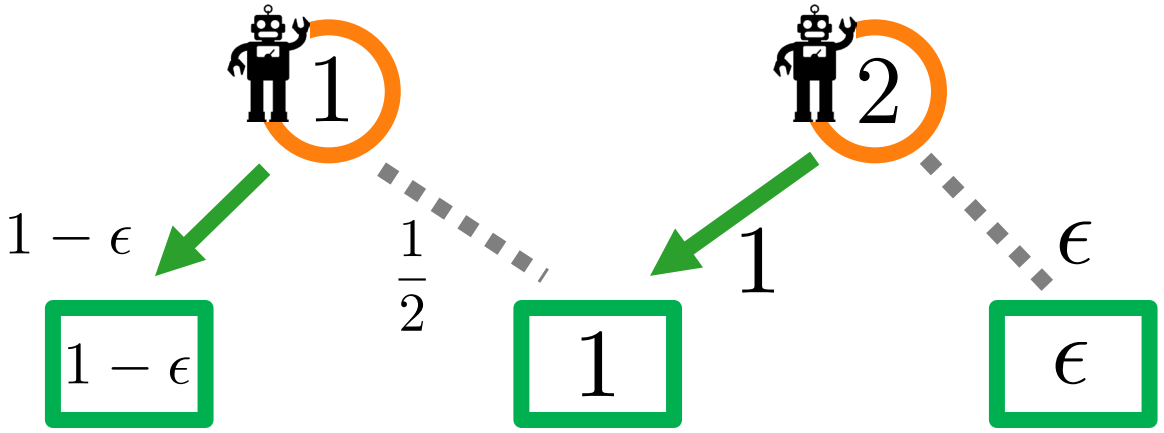
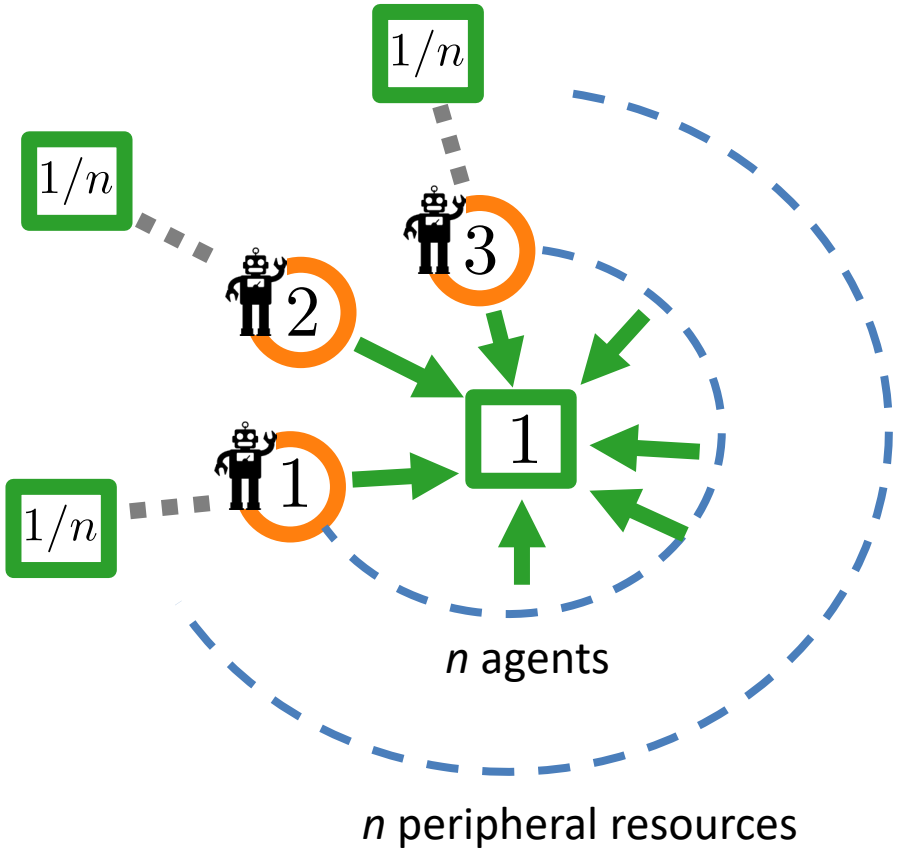


Q: Does this generalize?

A: No… PoA(equal share)=1/2 as well

Q: Does this generalize?

A: No: $\mathrm{PoA}(\text{equal share}) = \frac{1}{2}$



n agents on center

Each agent on center gets 1/n

Equal share over-incentivizes redundancy!

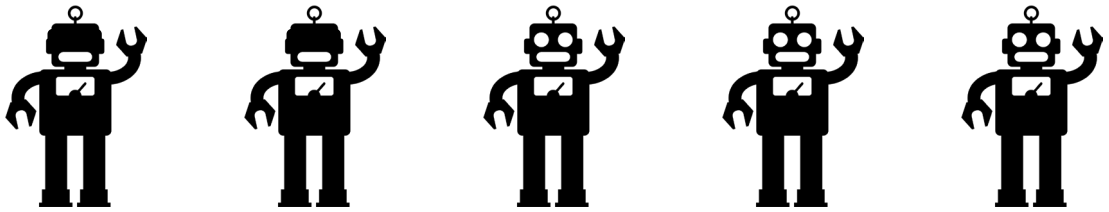
	Altruism	Equal Share
Intuition:	"Trusting" Agents	Promotes Redundancy
PoA:	$\frac{1}{2}$	$\frac{1}{2}$

No clear way to differentiate in general submodular games!

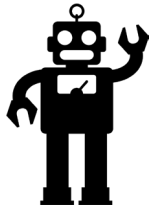
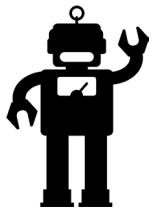
Note: in specific classes of games, more is known!

	Altruism	Equal Share
Intuition:	"Trusting" Agents	Promotes Redundancy
PoA:	$\frac{1}{2}$	$\frac{1}{2}$
Robustness:	???	???

Simple Starter question: what if K agents are "blind?"



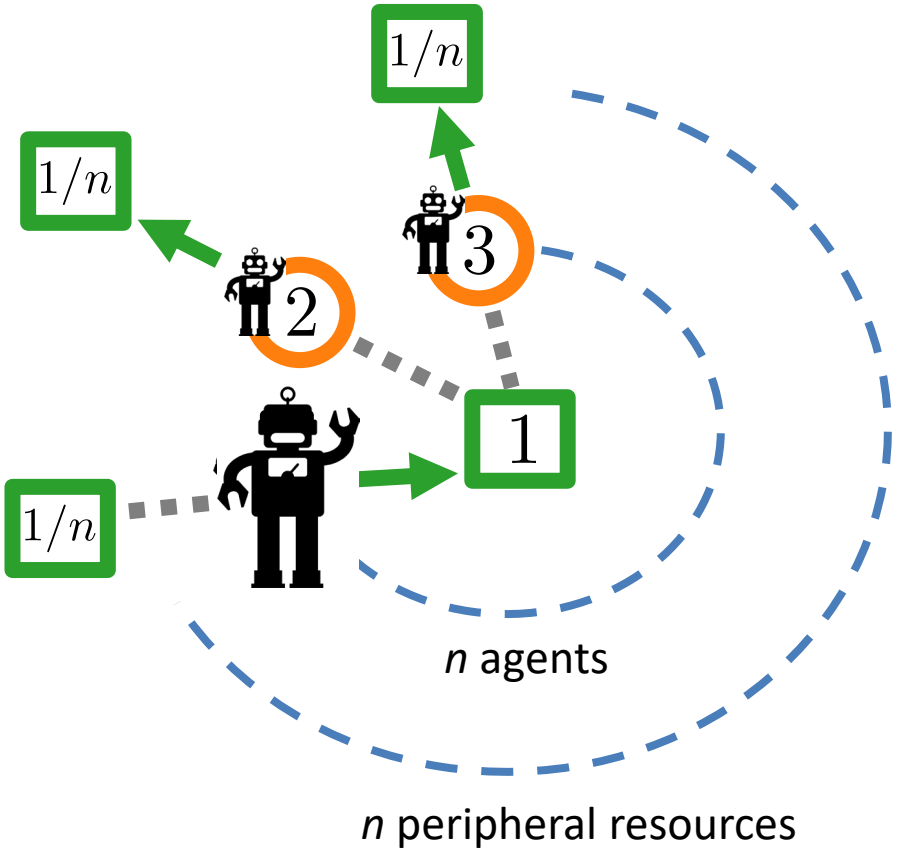
Simple Starter question: what if K agents are “blind?”

		Can see	Behavior
Nominal:		Resource Values Choices of other agents	Maximize as usual
Blind:		Only Resource Values	Select highest-value resource available

Q: what are $\begin{cases} \mathrm{PoA}(\mathrm{altruism}; K) \\ \mathrm{PoA}(\mathrm{equal\ share}; K) \end{cases}$

Q: Example 1?

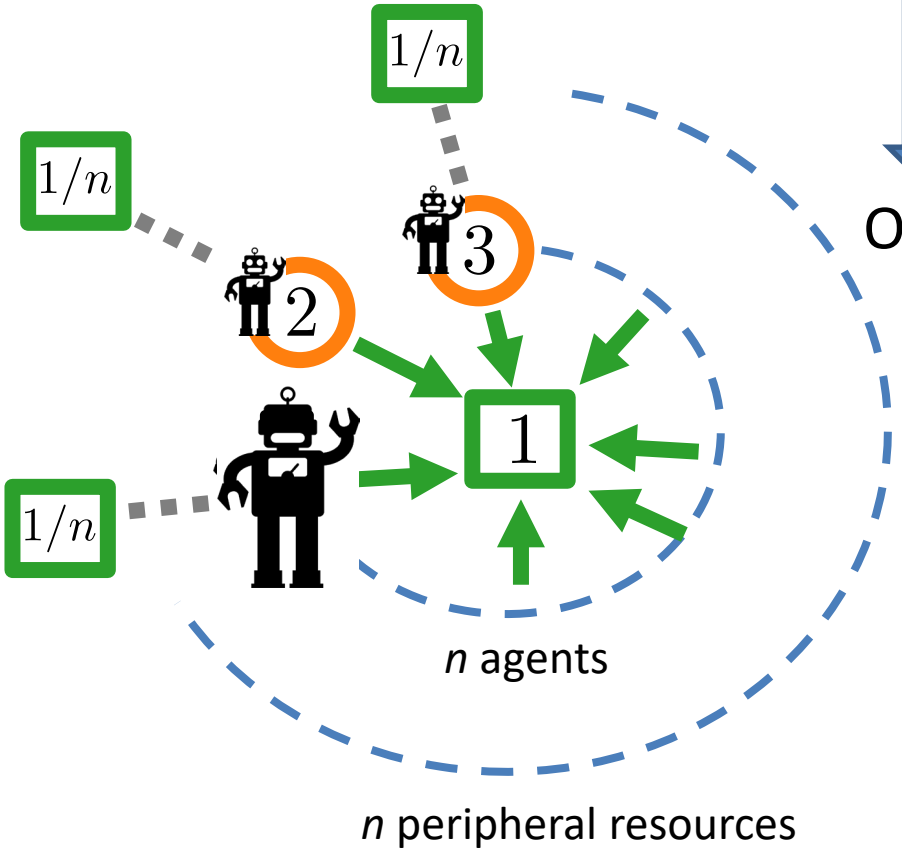
Blind agent chooses center



Others altruistic: go outside

$$\mathrm{PoA} = 1$$

Q: Example 1?



Blind agent chooses center

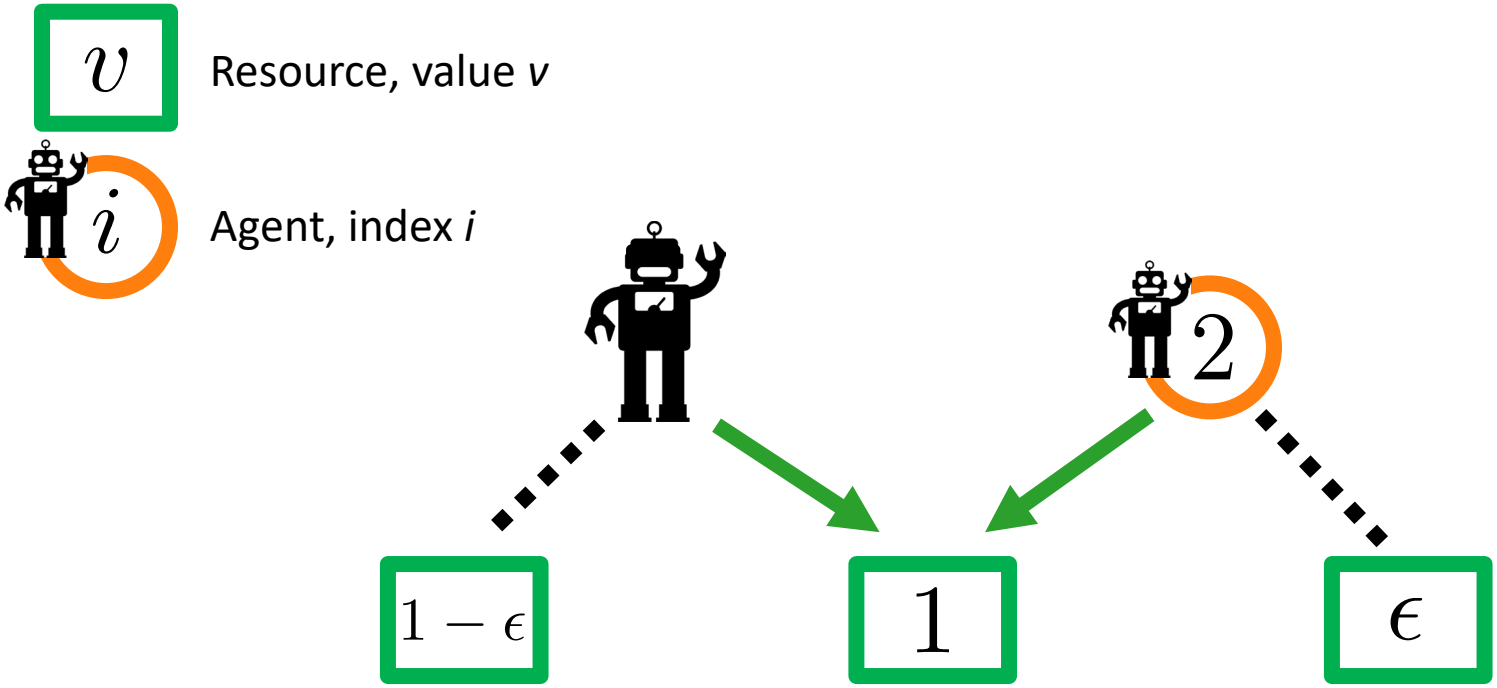
Others altruistic: go outside

$$\mathrm{PoA} = 1$$

Others Equal share: go center

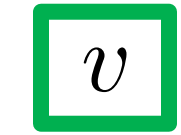
$$\mathrm{PoA} = \frac{1}{2}$$

Blind agent changes nothing!

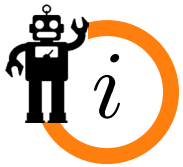


Blind agent always chooses **center.**

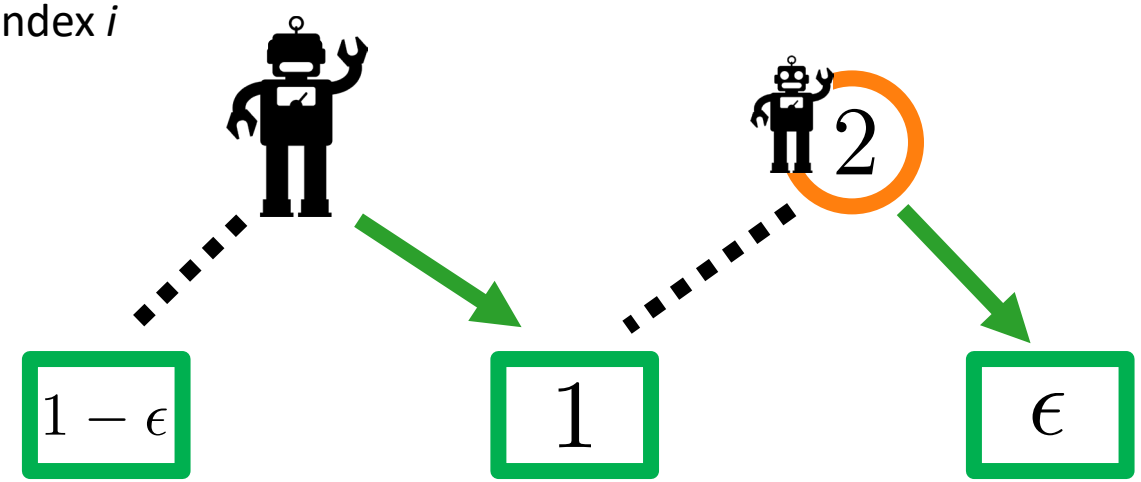
Nominal agent chooses **center** if equal share,



Resource, value *v*



Agent, index *i*



Blind agent always chooses **center.**

Nominal agent chooses **center** if equal share, **right** if altruistic.

$$\begin{cases} \text{PoA} = \frac{1}{2} \end{cases}$$

	Altruism		Equal Share	
	Nominal	Blinded	Nominal	Blinded
Example 1:	1	1	$\frac{1}{2}$	$\frac{1}{2}$
Example 2:	$\frac{1}{2}$	$\frac{1}{2}$	1	$\frac{1}{2}$

Suggests: if blindness is a risk, agents should be altruistic

Now, some theory to support this notion…

Theorem:

If K agents are blind to the choices of others, then the following are true (in all submodular games):

$$\begin{aligned}\mathrm{PoA}(\text{altruism}; K) &\geq \mathrm{PoA}(\text{equal share}; K) \\ &= \frac{1}{2+K}\end{aligned}$$

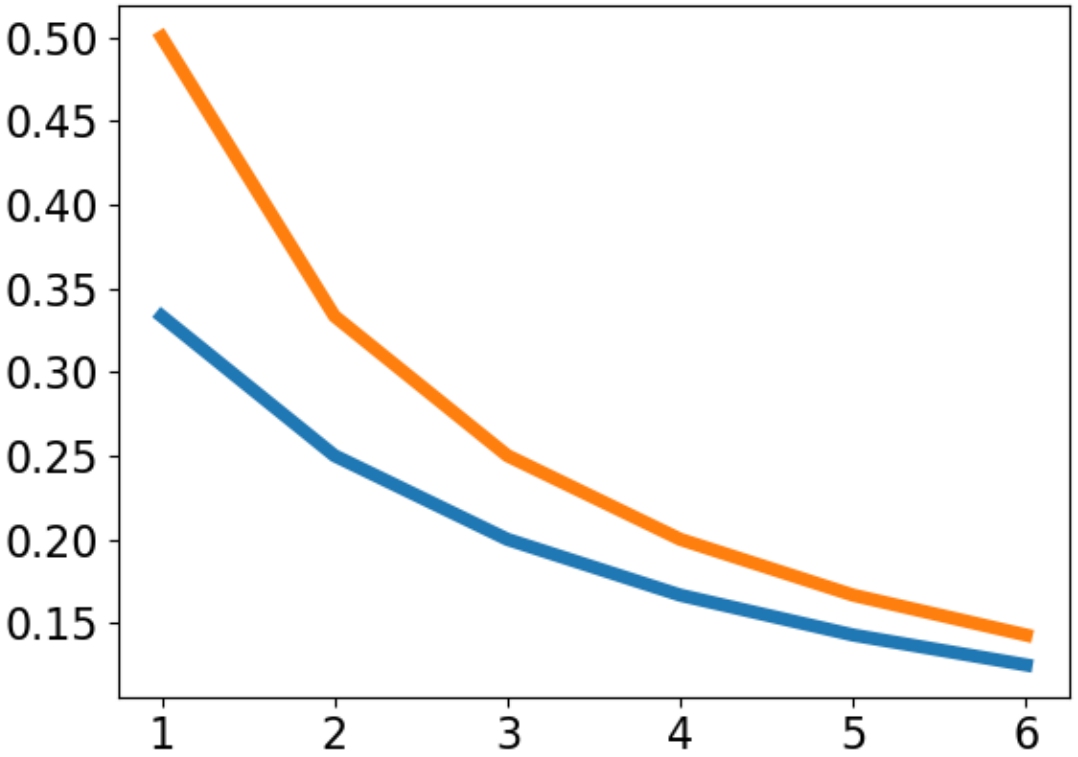
In fact,

$$\mathrm{PoA}(\text{altruism}; K) = \frac{1}{1+K}$$

Grimsman, Seaton, Marden and **P. N. Brown**., "The Cost of Denied Observation in Multiagent Submodular Optimization," *CDC2020*

$\mathrm{PoA}(\text{altruism}; K)$ (exact)

$\mathrm{PoA}(\text{equal share}; K)$ (exact)



Grimsman, Seaton, Marden and **P. N. Brown**., "The Cost of Denied Observation in Multiagent Submodular Optimization," *CDC2020*

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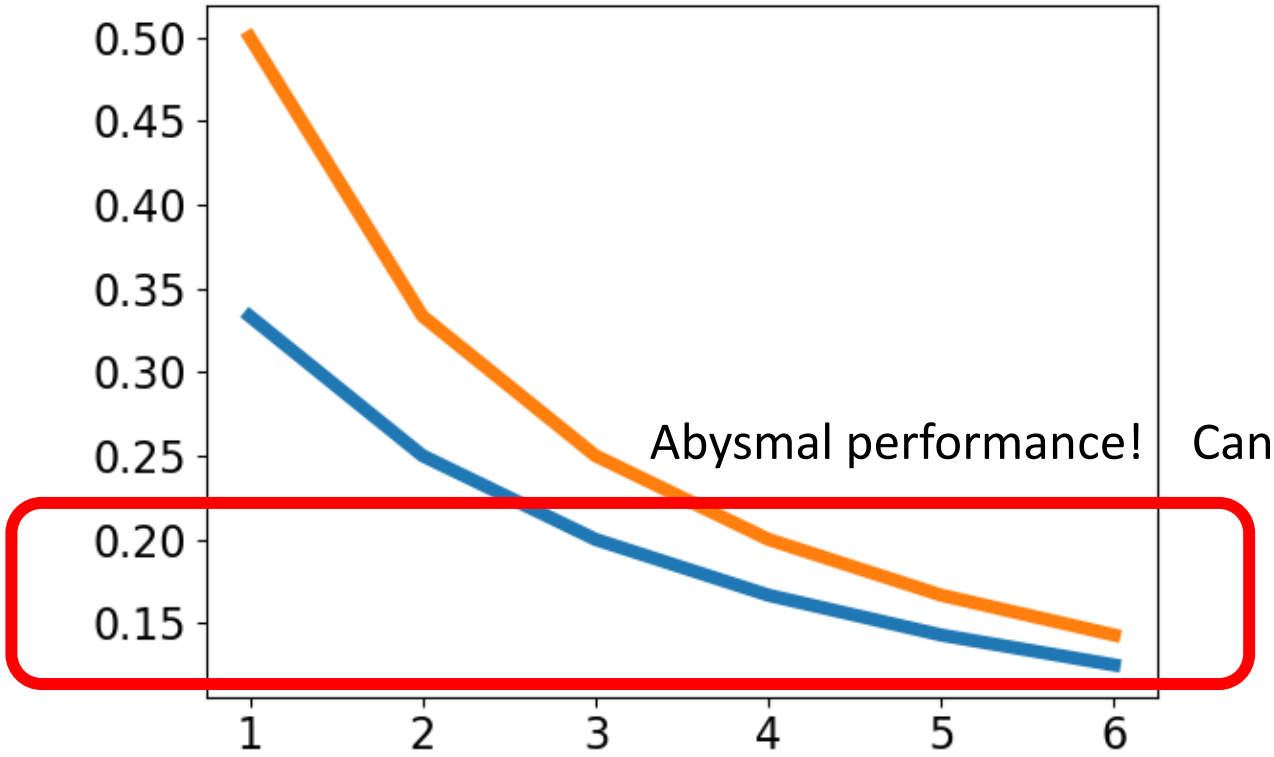

Abysmal performance! Can we do better?

Grimsman, Seaton, Marden and **P. N. Brown**., "The Cost of Denied Observation in Multiagent Submodular Optimization," *CDC2020*

Theorem:

If K agents are blind and their "satisfaction" is S, then

$$\mathrm{PoA}(\mathrm{altruism}; K, S) \geq \frac{1}{1 + K - S}$$

Plainly:

The only way an outcome can be **very bad** is if S=0 (no agent cares much about what action it's choosing)

J. Seaton and **P. N. Brown**, "All Low-Quality Equilibria are Unstable in Submodular Maximization with Communication-Denied Agents" L-CSS, 2022

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So what?

Compromised agents shouldn't take their perception too seriously, and should randomize their choices!

J. Seaton and **P. N. Brown**, "All Low-Quality Equilibria are Unstable in Submodular Maximization with Communication-Denied Agents" L-CSS, 2022

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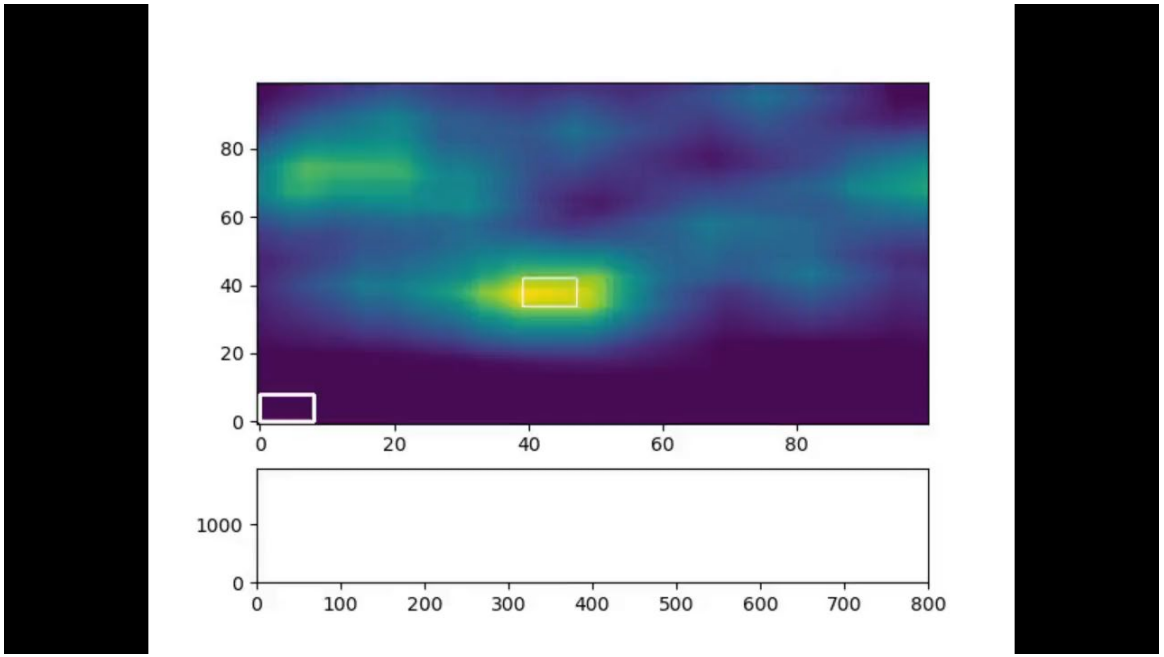
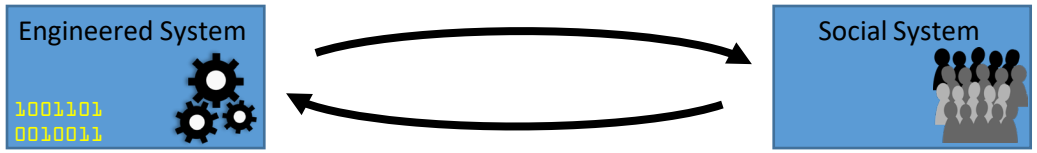


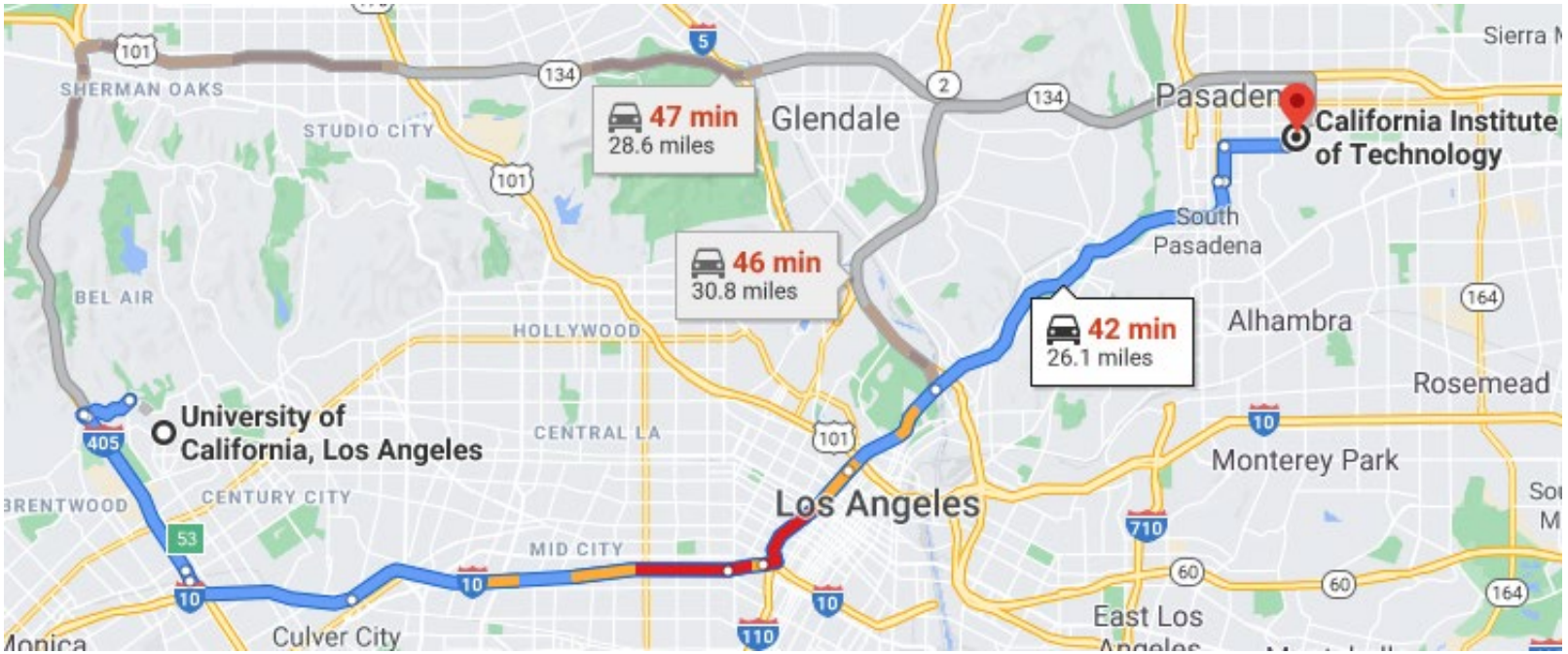
J. Seaton and **P. N. Brown**, "All Low-Quality Equilibria are Unstable in Submodular Maximization with Communication-Denied Agents“ L-CSS, 2022

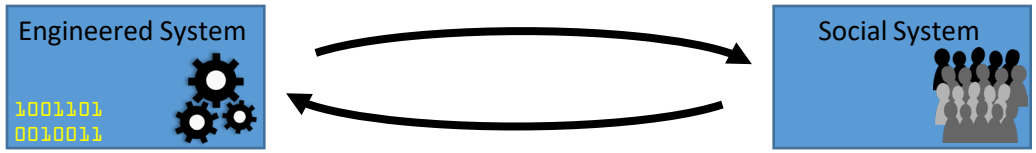
How should interacting autonomous agents behave in **compromised** environments?

1. If others may be blind, be altruistic!
2. If you are blind, dance around!



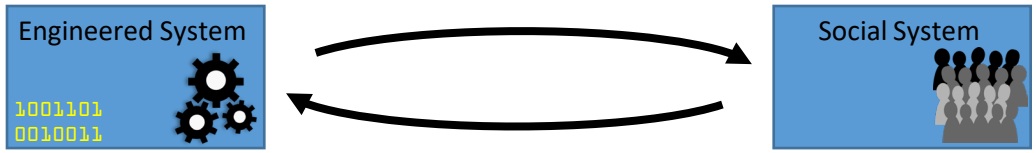
Choosing Routes in Highway Networks





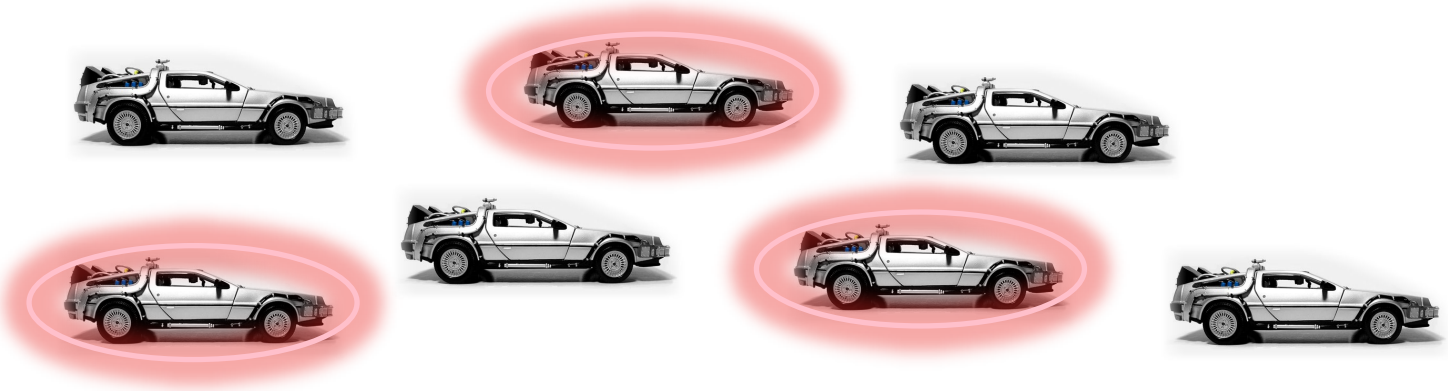
Choosing Routes in Highway Networks

Agenda: pose simple model
Explore behavior in its context



Choosing Routes in Highway Networks

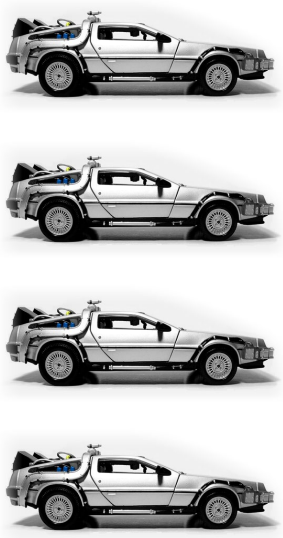
?

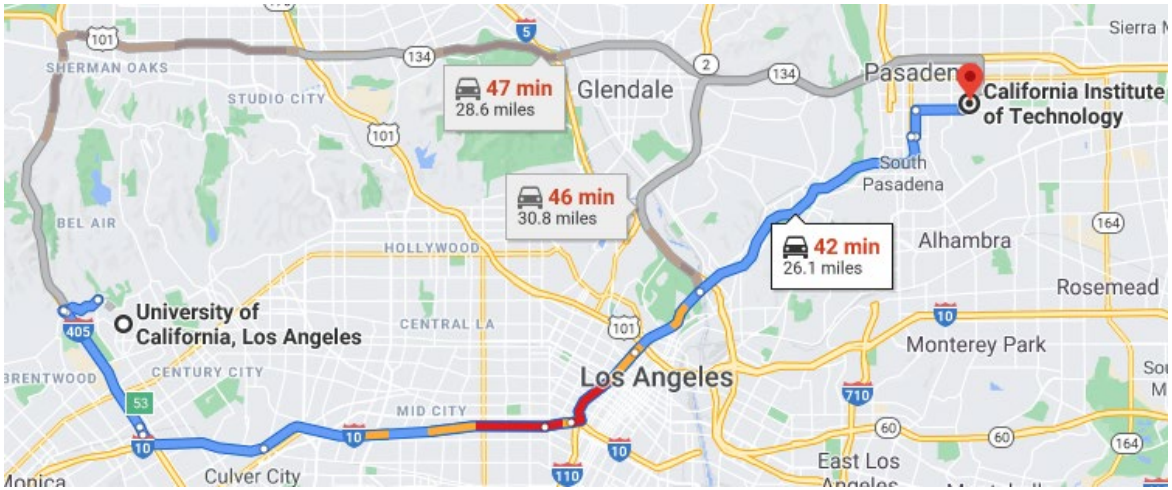


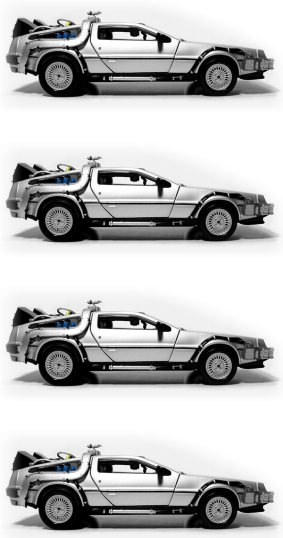
Agenda: pose simple model

Explore behavior in its context

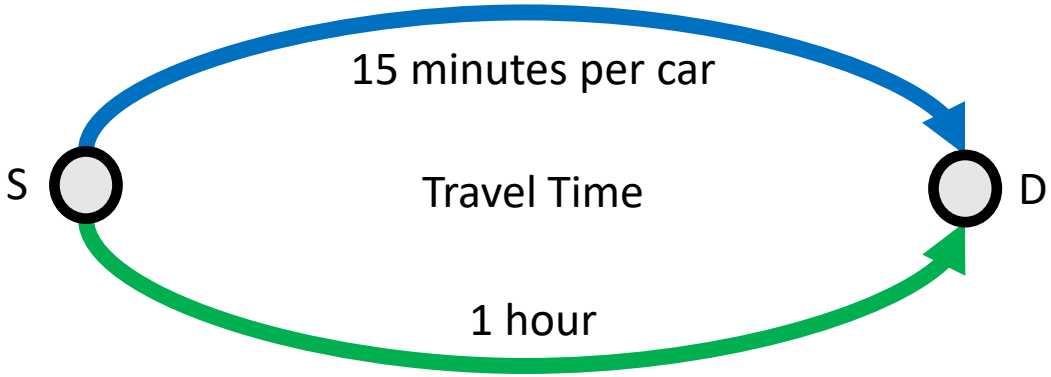
Question: should self-driving cars be altruistic?




47 min
28.6 miles
46 min
30.8 miles
42 min
26.1 miles
Glendale
Pasadena
California Institute of Technology
South Pasadena
Alhambra
Rosemead
Monterey Park
East Los Angeles
Los Angeles
University of California, Los Angeles
SHERMAN OAKS
STUDIO CITY
BEL AIR
HOLLYWOOD
CENTRAL LA
CENTURY CITY
MID CITY
Culver City



Fast, if empty
Congestion-sensitive



Slow no matter what
Congestion-**in**sensitive

Fast, if empty
Congestion-sensitive

15 minutes

15 minutes per car

S

Travel Time

D

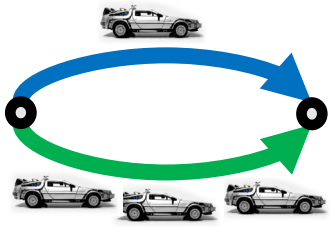
1 hour

1 hour

1 hour

Slow no matter what
Congestion-**in**sensitive

Traffic



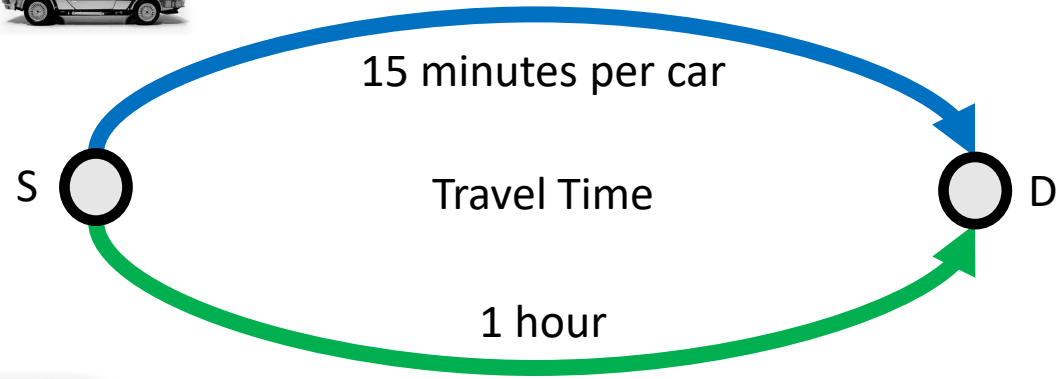
Total Time

3.25 hours

30 minutes

Fast, if empty
Congestion-sensitive

30 minutes

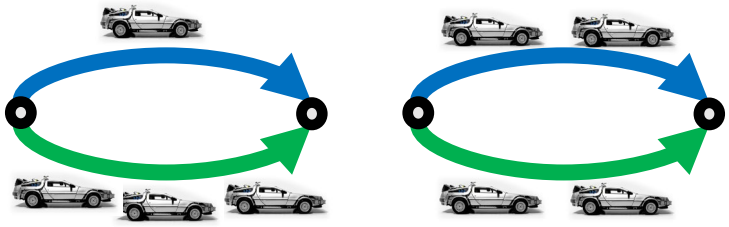


1 hour

Slow no matter what
Congestion-**in**sensitive

1 hour

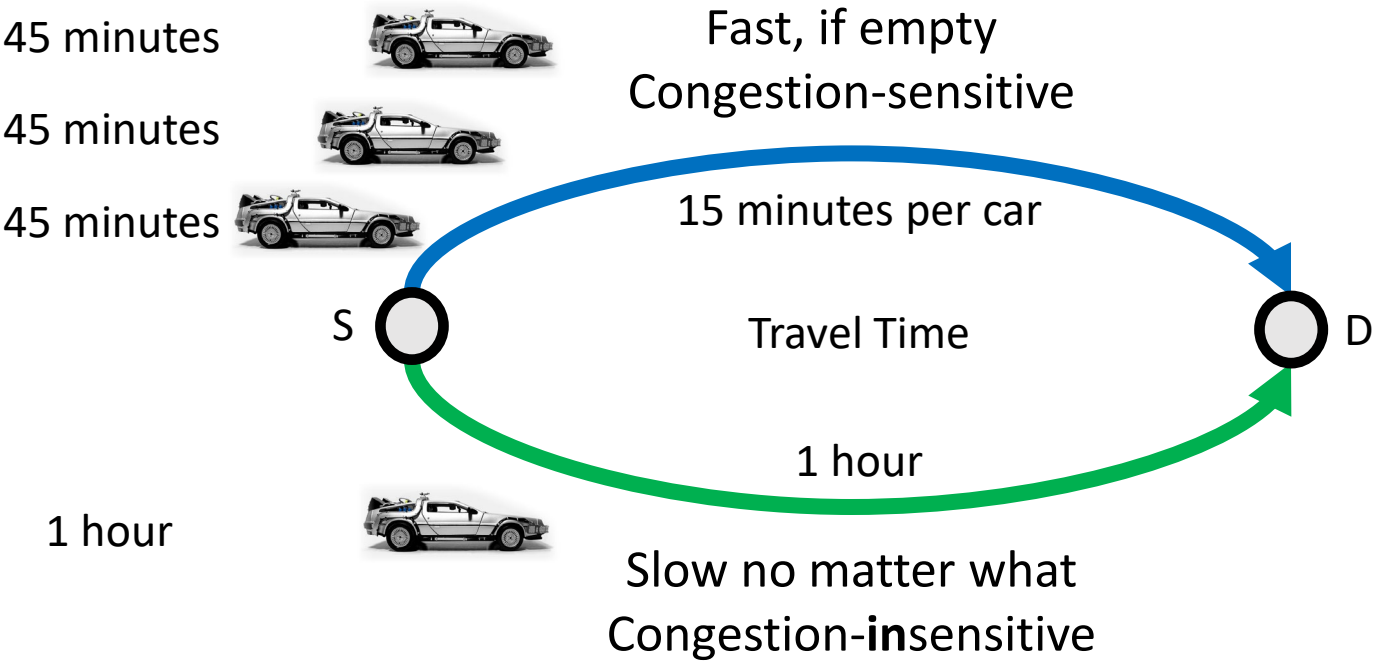
Traffic

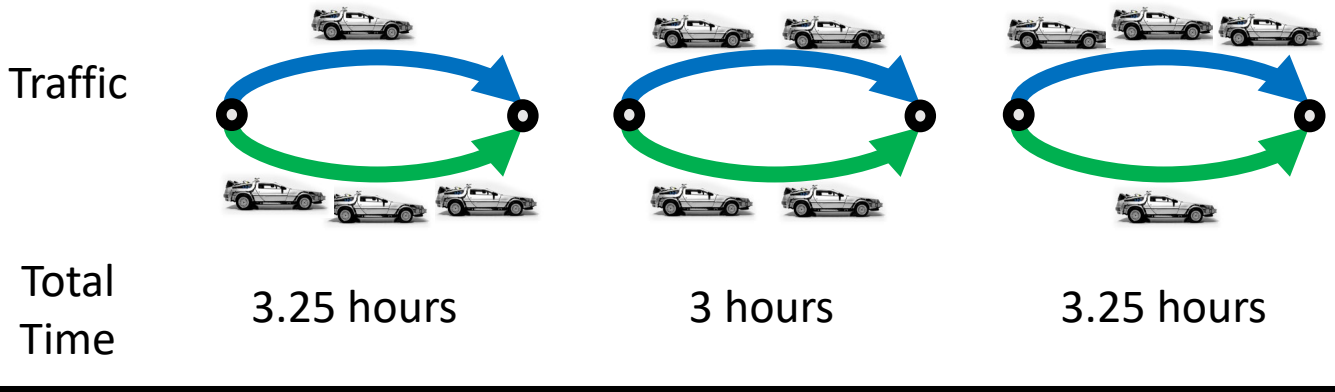


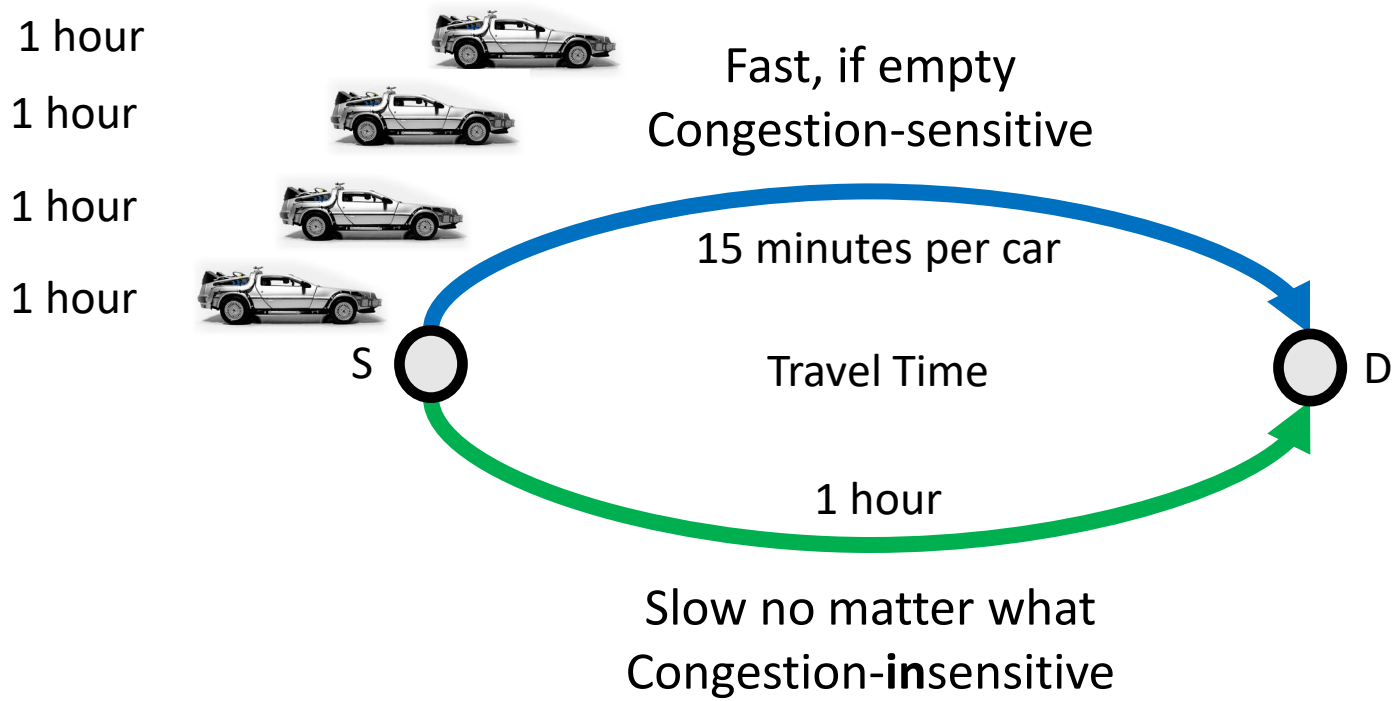
Total Time

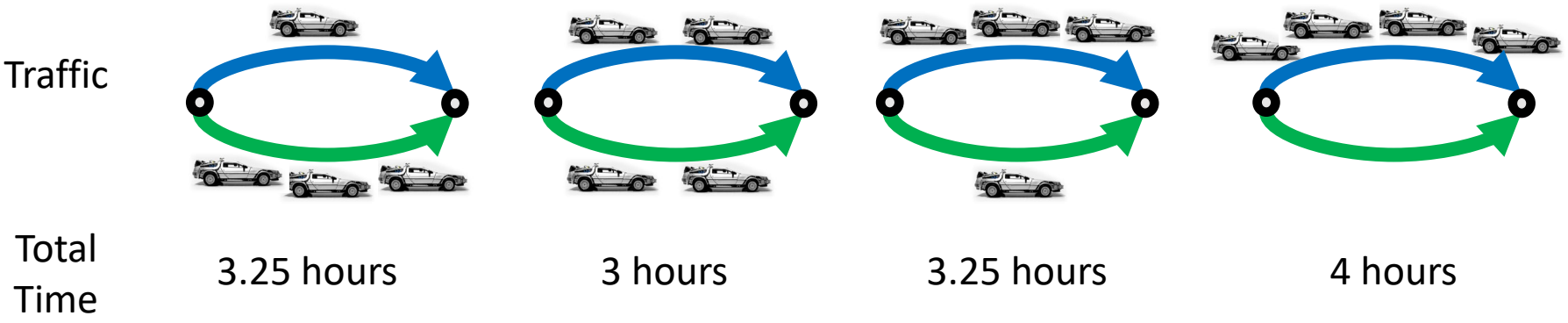
3.25 hours

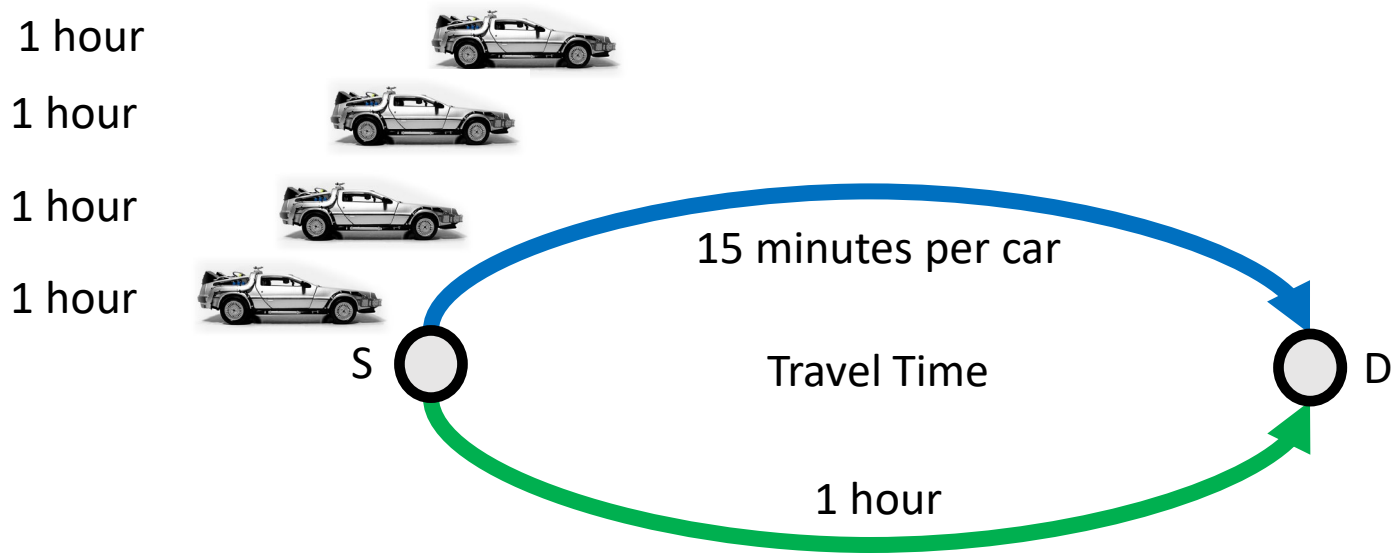
3 hours


45 minutes
45 minutes
45 minutes
Fast, if empty
Congestion-sensitive
15 minutes per car
S
Travel Time
D
1 hour
1 hour
Slow no matter what
Congestion-insensitive

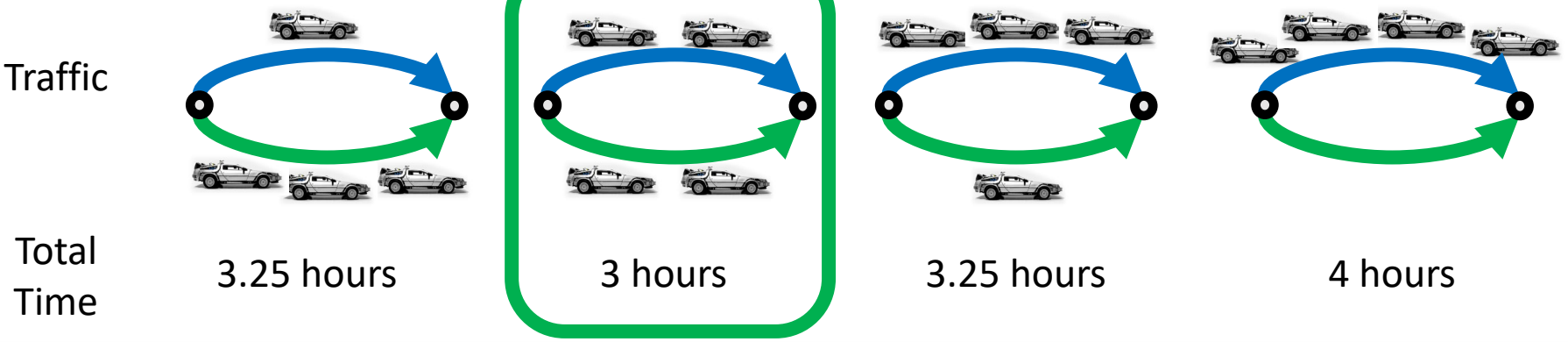

Traffic
Total Time
3.25 hours
3 hours
3.25 hours

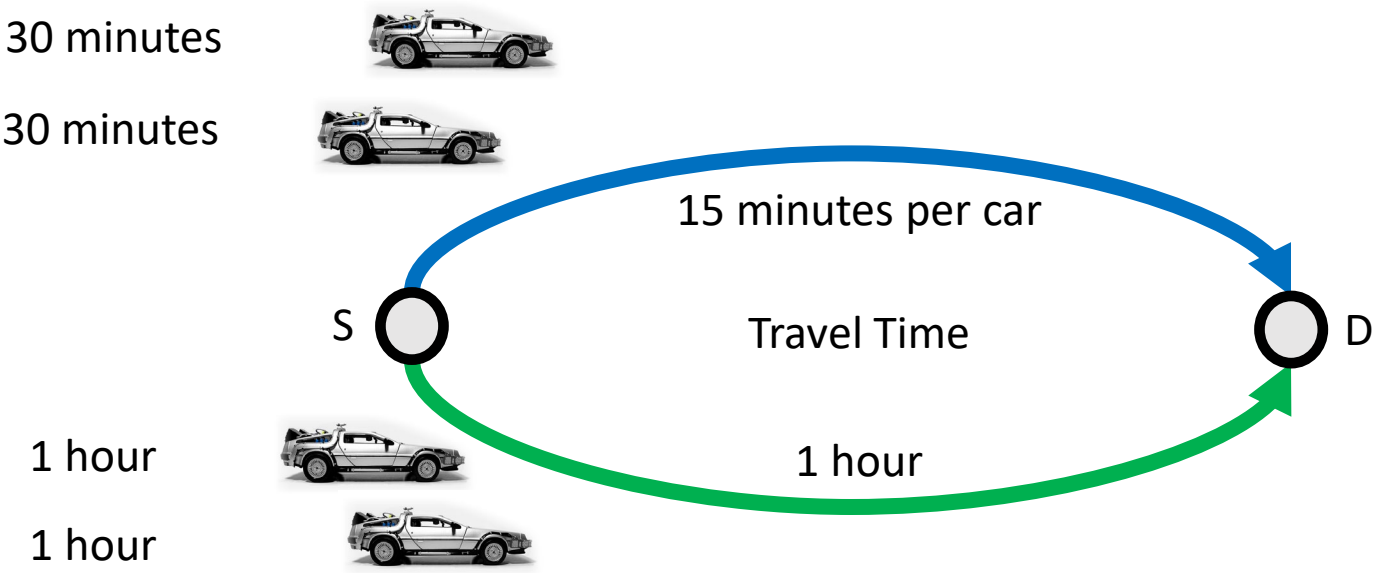

1 hour
1 hour
1 hour
1 hour
Fast, if empty
Congestion-sensitive
15 minutes per car
S
Travel Time
D
1 hour
Slow no matter what
Congestion-insensitive


Traffic
Total Time
3.25 hours
3 hours
3.25 hours
4 hours



Best option!
(Pareto optimal)





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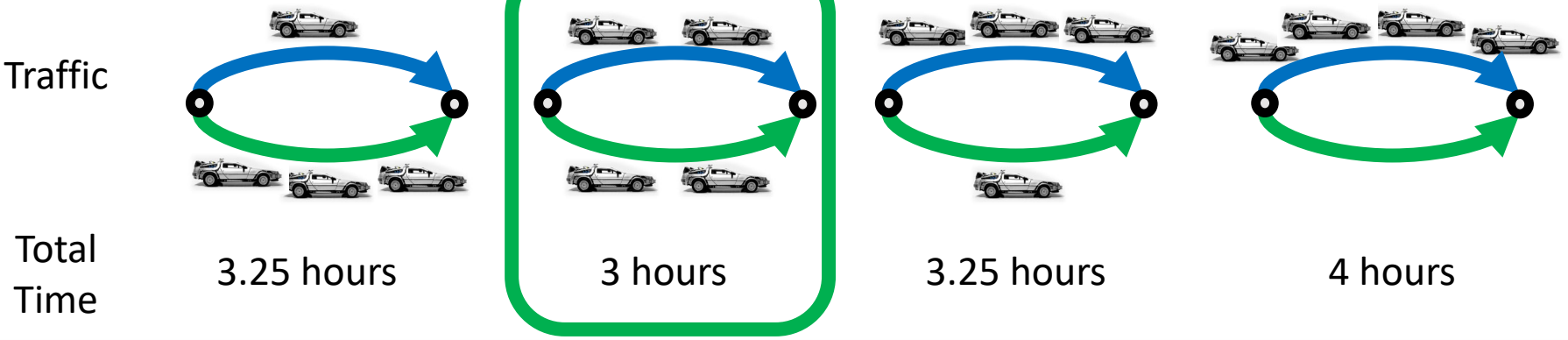
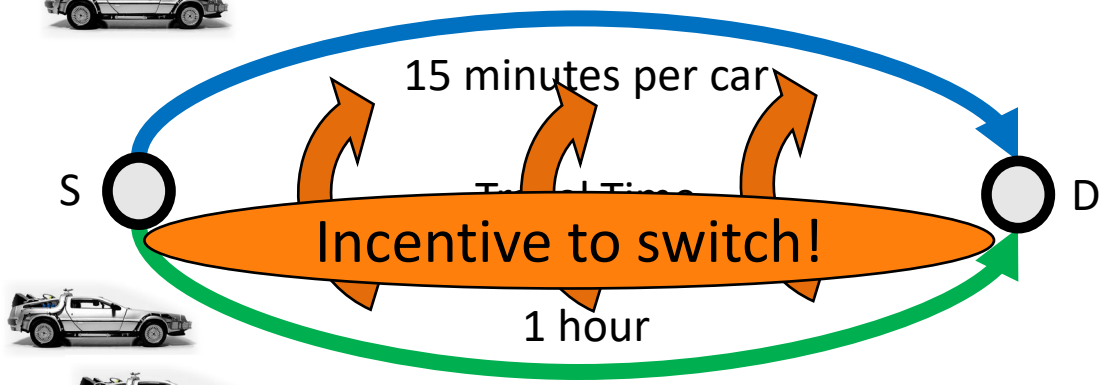


Altruistic self-driving cars?

30 minutes

30 minutes



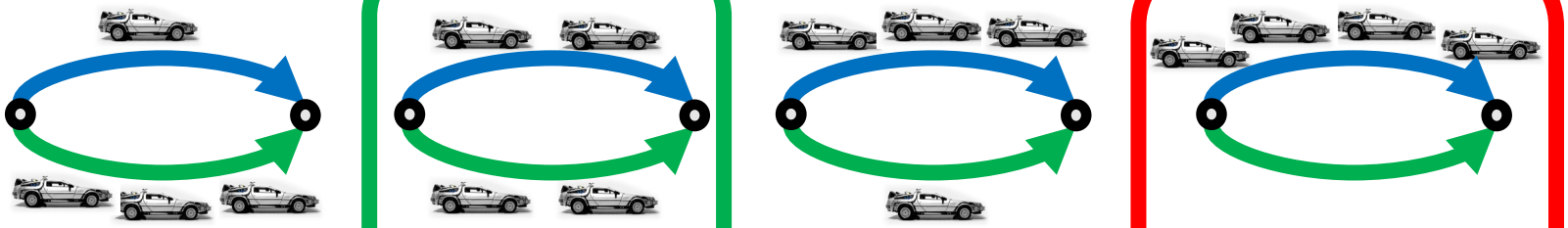
1 hour

1 hour

Best option!
(Pareto optimal)

Selfish traffic
is like this!

Traffic



Total Time

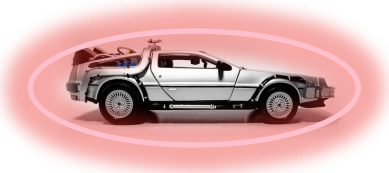
3.25 hours

3 hours

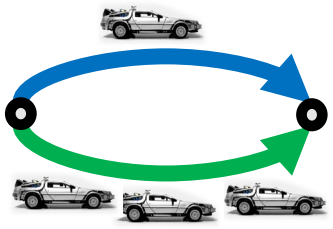
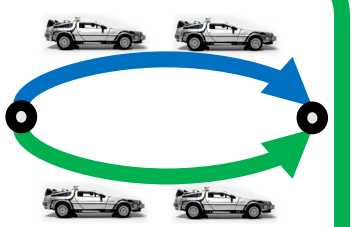
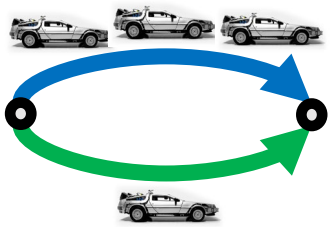
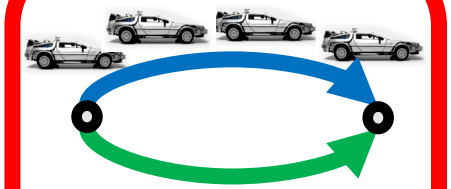
3.25 hours

4 hours

Altruistic self-driving cars?



Altruism: act like there is 2x actual traffic

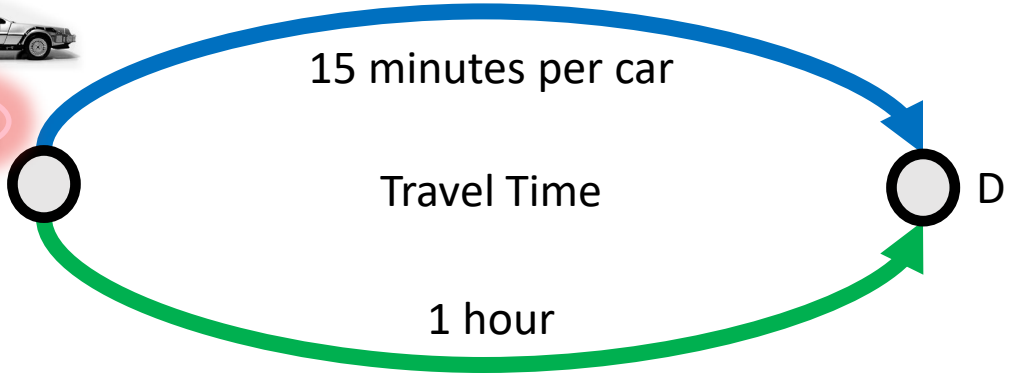
		Best option! (Pareto optimal)		Selfish traffic is like this!
Traffic				
Total Time	3.25 hours	3 hours	3.25 hours	4 hours

1 hour

1 hour

1 hour

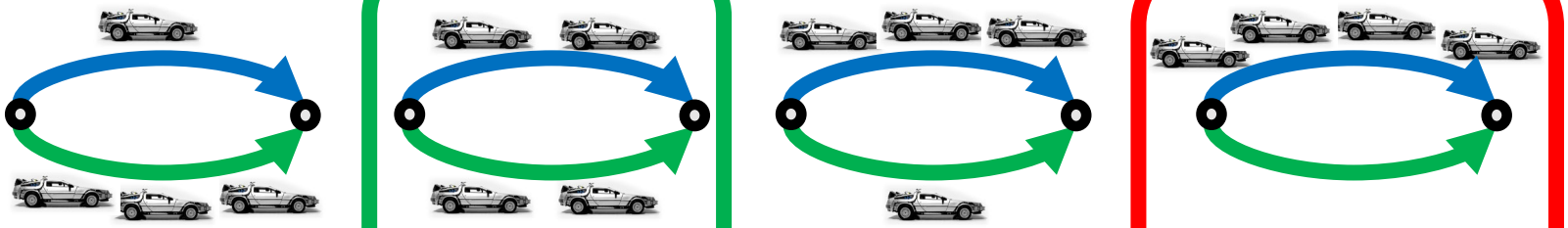
1 hour



Best option!
(Pareto optimal)

Selfish traffic
is like this!

Traffic



Total Time

3.25 hours

3 hours

3.25 hours

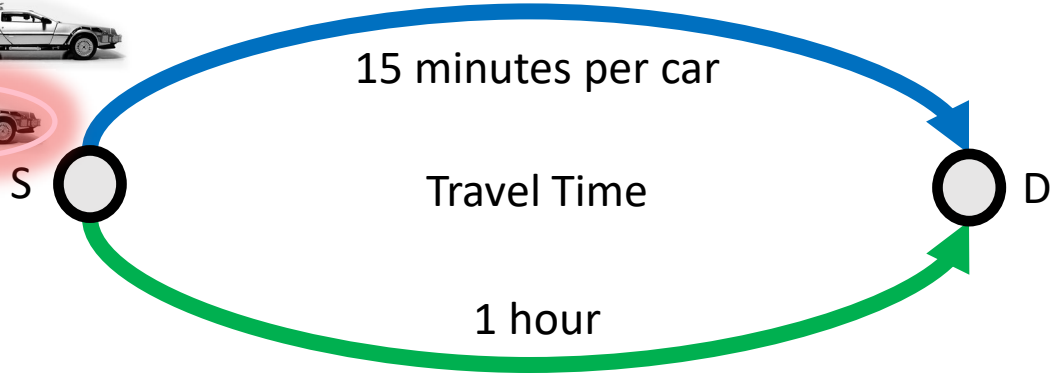
4 hours

1 hour

1 hour

1 hour

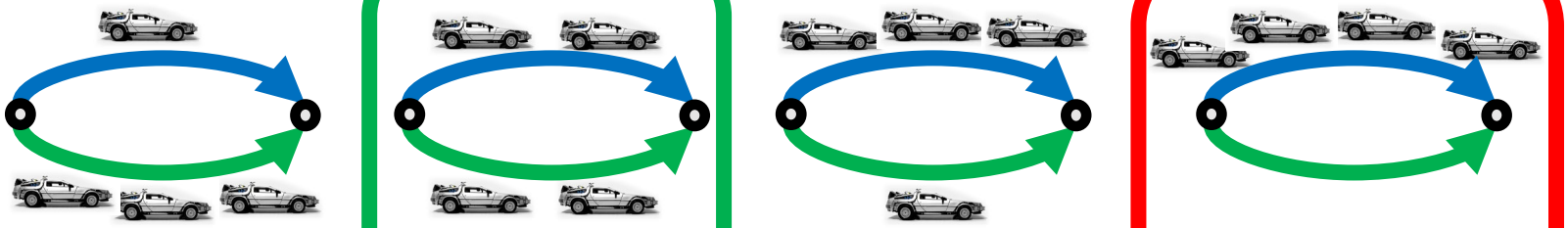
2 hours



Best option!
(Pareto optimal)

Selfish traffic
is like this!

Traffic



Total Time

3.25 hours

3 hours

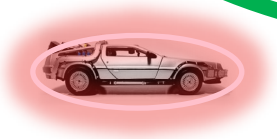
3.25 hours

4 hours

45 minutes

45 minutes

45 minutes



1 hour

15 minutes per car

S

Travel Time

D

1 hour

Best option!
(Pareto optimal)

Traffic

Total Time

3.25 hours

3 hours

3.25 hours

4 hours

45 minutes

45 minutes

90 minutes

15 minutes per car

S

Travel Time

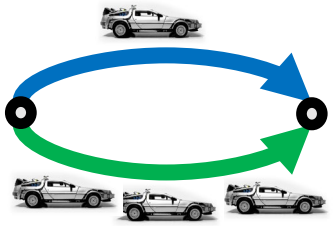
D

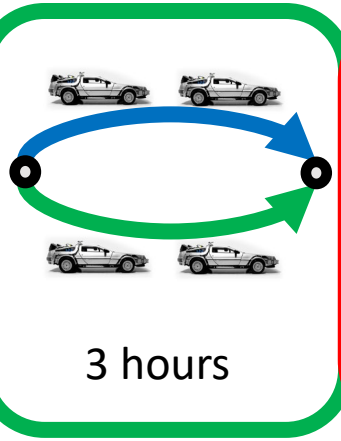
1 hour

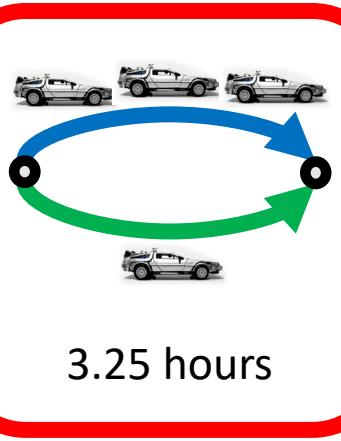
1 hour

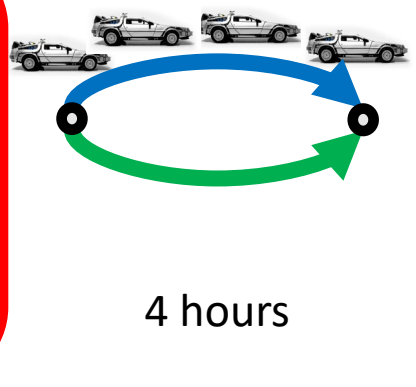
Best option!
(Pareto optimal)

Traffic









Total Time

3.25 hours

3 hours

3.25 hours

4 hours

30 minutes

30 minutes

15 minutes per car

S

Travel Time

D

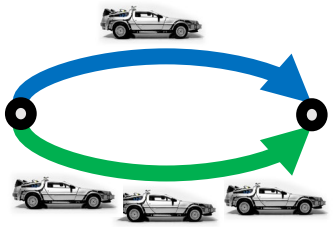
1 hour

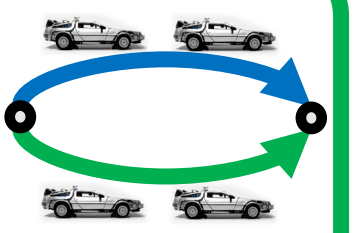
1 hour

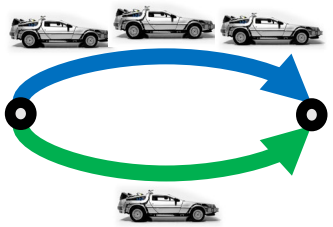
1 hour

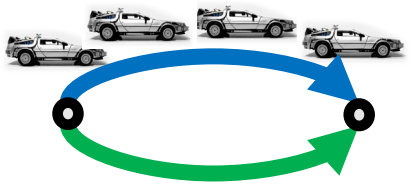
Best option!
(Pareto optimal)

Traffic









Total Time

3.25 hours

3 hours

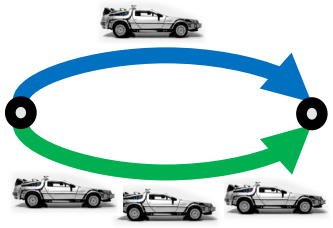
3.25 hours

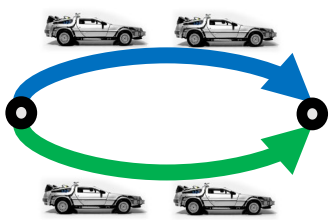
4 hours

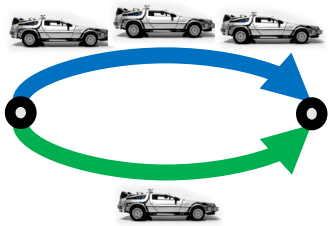
Altruistic self-driving cars:

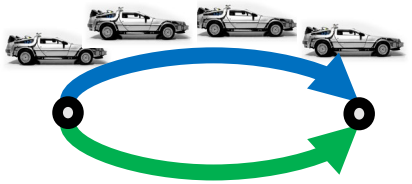
- Improve congestion
- Even if only some are altruistic
- Without making others worse off
- Unambiguously good?

Traffic









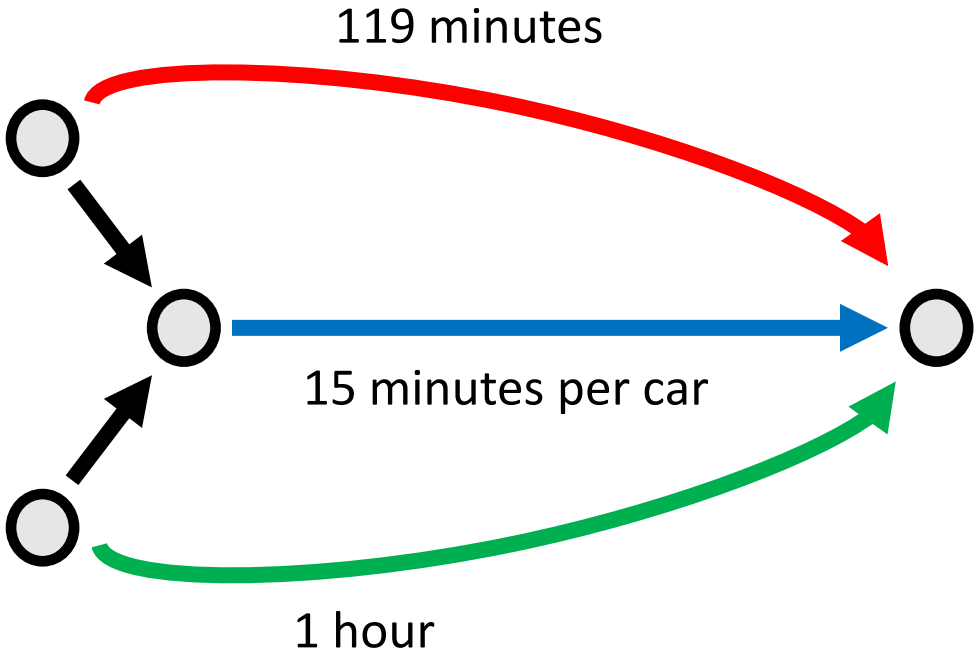
Total Time

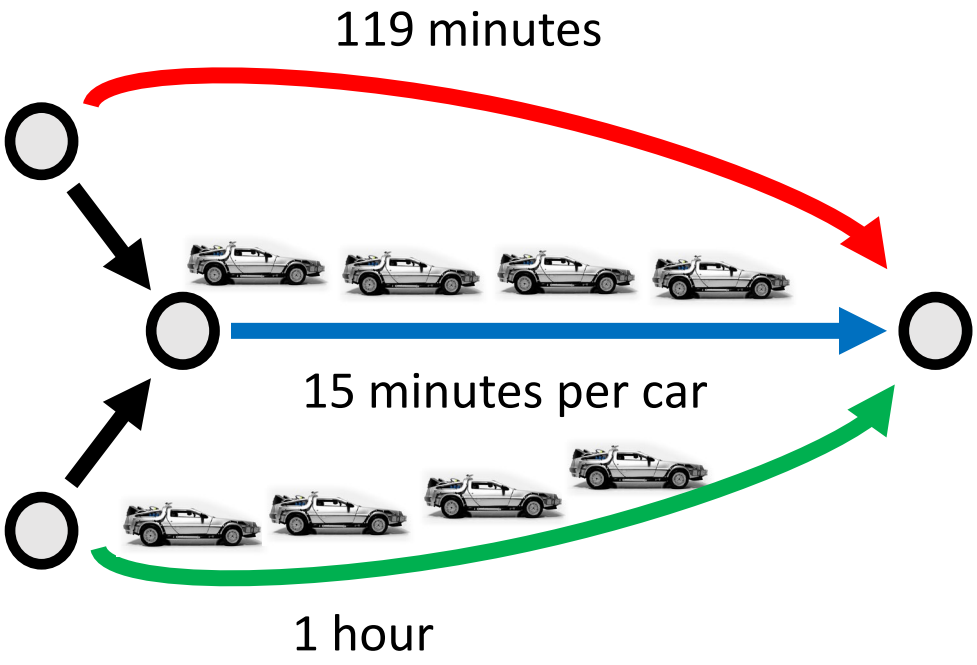
3.25 hours

3 hours

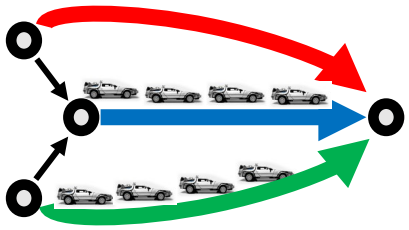
3.25 hours

4 hours


119 minutes
15 minutes per car
1 hour



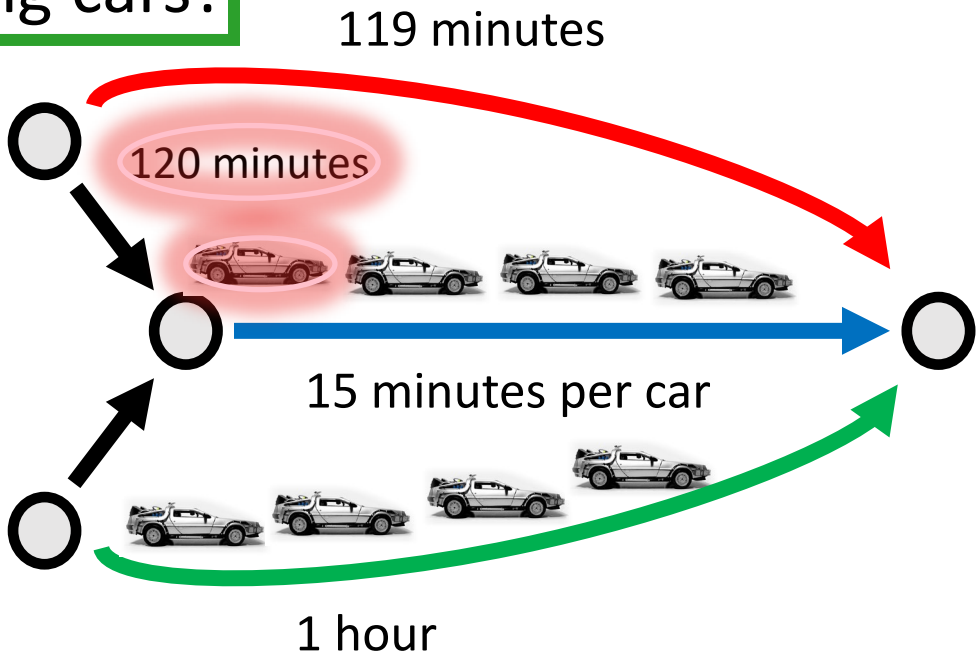
Selfish Traffic



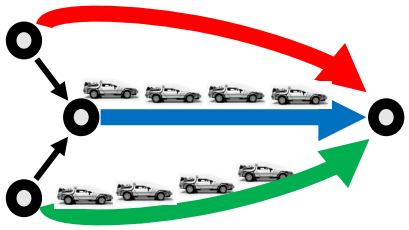
Total Time

8 hours

Altruistic self-driving cars?



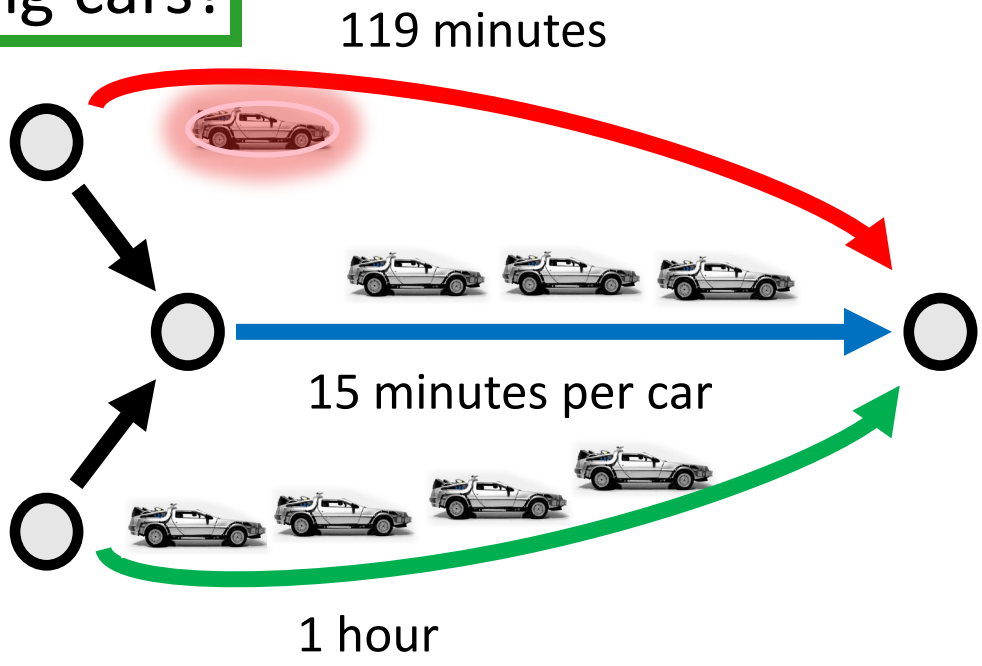
Selfish Traffic



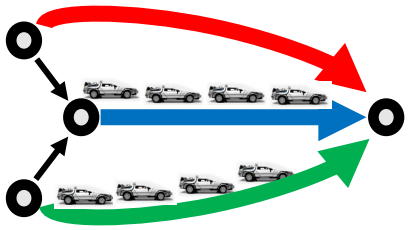
Total Time

8 hours

Altruistic self-driving cars?



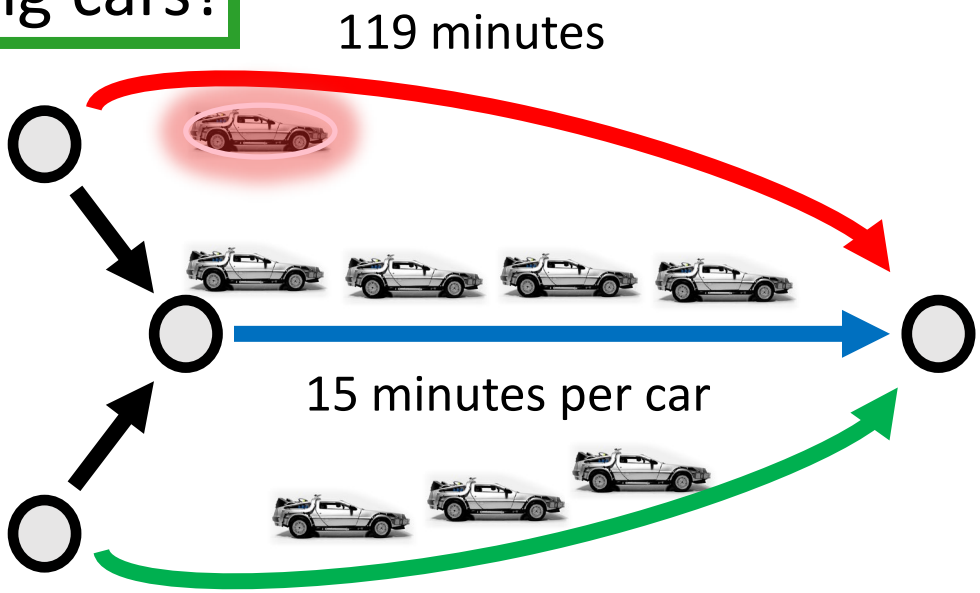
Selfish Traffic



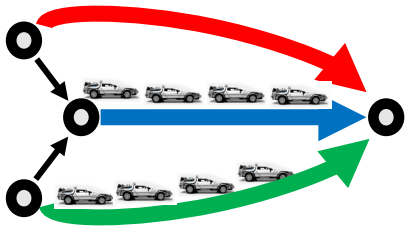
Total Time

8 hours

Altruistic self-driving cars?

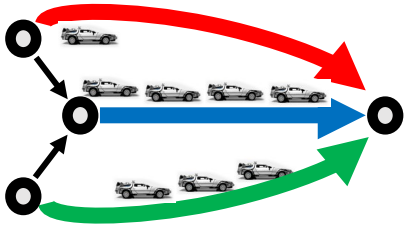


Selfish Traffic



8 hours

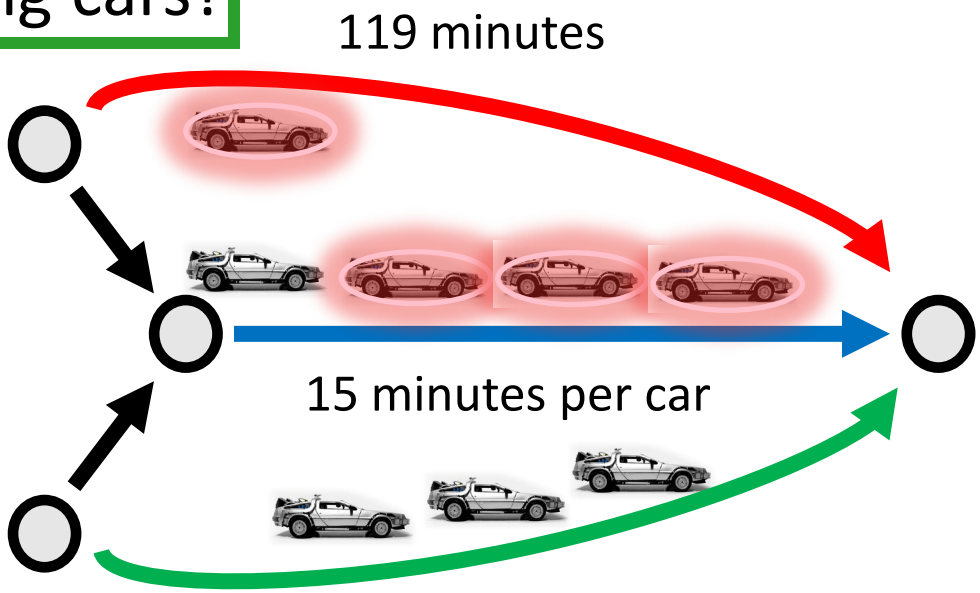
1 Altruistic Car



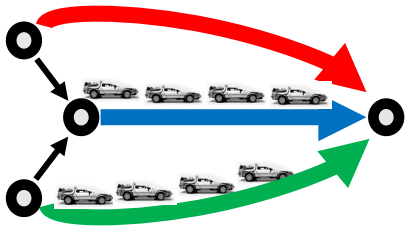
9 hours

Total Time

Altruistic self-driving cars?

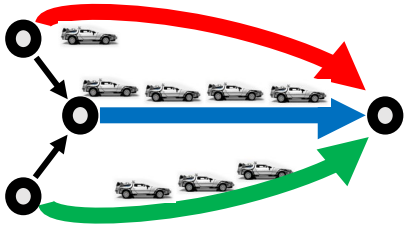


Selfish Traffic



8 hours

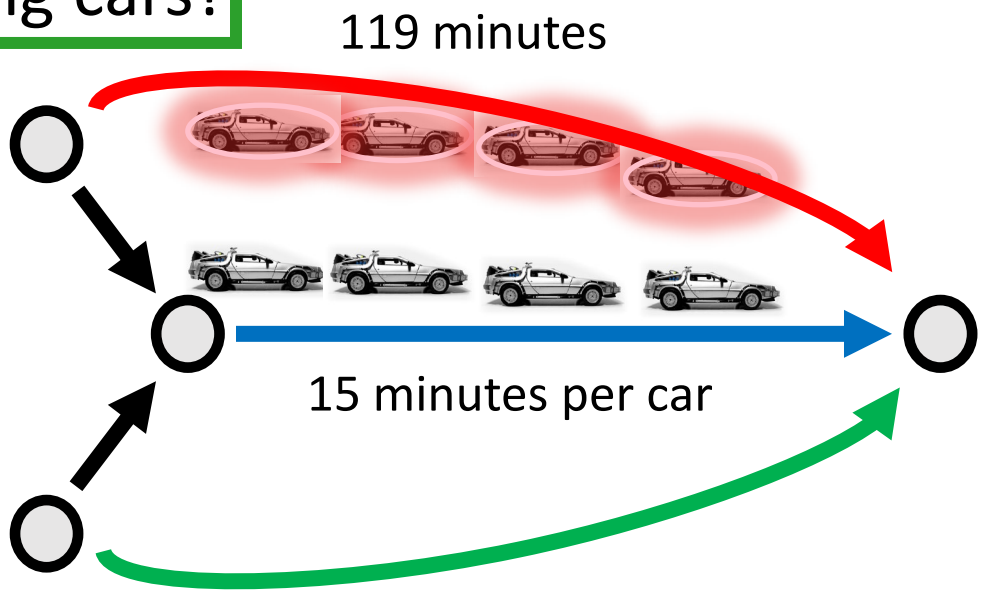
1 Altruistic Car



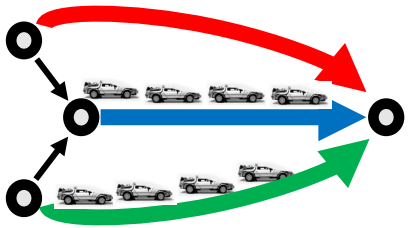
9 hours

Total Time

Altruistic self-driving cars?

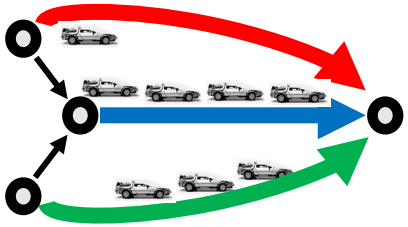


Selfish Traffic



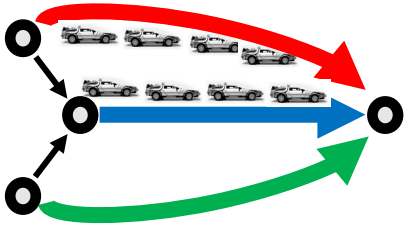
8 hours

1 Altruistic Car



9 hours

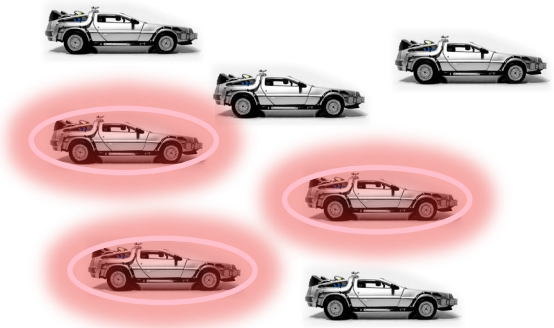
4 Altruistic Cars



12 hours

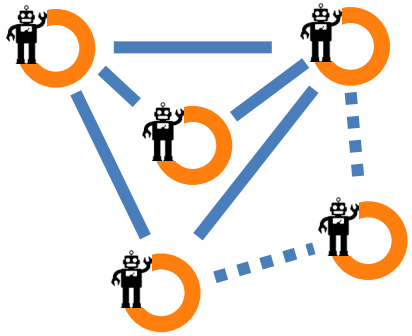
Total Time

Socially-Embedded Autonomy



- Altruism helpful in some problems
- Can be harmful in complex networks

Compromised Multiagent Systems



- If others are blind, be altruistic
- If you are blind, dance around!

My Website

Technical Talks

ECCS-2013779

FA9550-23-1-0171