

# 15-784 (CMU)

## Foundations of Cooperative AI

See also: [Foundations of Cooperative AI Lab \(FOCAL\)](#),  
[Electronic Marketplaces Lab \(EM\)](#)



*Vincent Conitzer*



*Caspar Oesterheld*



*Tuomas Sandholm*

# Outline for today / this week

- Logistics
- High-level intro / motivation
- Quickly touching on all kinds of topics in the course!
  - Start identifying possible projects from day 1
  - Let us know if you want more references on any topic!



# The Making of a Fly: The Genetics of Animal Design (Paperback)

by Peter A. Lawrence

[Return to product information](#)

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## Price at a Glance

List Price: ~~\$70.00~~

**Used:** from **\$35.54**

**New:** from **\$1,730,045.91**

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All

New (2 from \$1,730,045.91)

Used (15 from \$35.54)

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### New 1-2 of 2 offers

Price + Shipping	Condition	Seller Information	Buying Options
<b>\$1,730,045.91</b> + \$3.99 shipping	New	Seller: <b>profnath</b> Seller Rating: <b>★★★★★ 93% positive</b> over the past 12 months. (8,193 total ratings) In Stock. Ships from NJ, United States. <a href="#">Domestic shipping rates</a> and <a href="#">return policy</a> . Brand new, Perfect condition, Satisfaction Guaranteed.	<input type="button" value="Add to Cart"/> or <a href="#">Sign in</a> to turn on 1-Click ordering.
<b>\$2,198,177.95</b> + \$3.99 shipping	New	Seller: <b>bordeebook</b> Seller Rating: <b>★★★★★ 93% positive</b> over the past 12 months. (125,891 total ratings) In Stock. Ships from United States. <a href="#">Domestic shipping rates</a> and <a href="#">return policy</a> . New item in excellent condition. Not used. May be a publisher overstock or have slight shelf wear. Satisfaction guaranteed!	<input type="button" value="Add to Cart"/> or <a href="#">Sign in</a> to turn on 1-Click ordering.

From *The Atlantic*, "[Want to See How Crazy a Bot-Run Market Can Be?](#)"

By [James Fallows](#)

April 23, 2011

OLIVIA SOLON

BUSINESS 04.27.2011 03:35 PM

# How A Book About Flies Came To Be Priced \$24 Million On Amazon

Two booksellers using Amazon's algorithmic pricing to ensure they were generating marginally more revenue than their main competitor ended up pushing the price of a book on evolutionary biology — Peter Lawrence's *The Making of a Fly* — to \$23,698,655.93. [partner id="wireduk"]The book, which was published in 1992, is out of print but is commonly [...]

Two booksellers using Amazon's algorithmic pricing to ensure they were generating marginally more revenue than their main competitor ended up pushing the price of a book on evolutionary biology -- Peter Lawrence's *The Making of a Fly* -- to \$23,698,655.93.

[partner id="wireduk"]The book, which was published in 1992, is out of print but is commonly used as a reference text by [fly experts](#). A post doc student working in Michael Eisen's lab at UC Berkeley first discovered the pricing glitch when looking to buy a copy. As [documented on Eisen's blog](#), it was discovered that Amazon had 17 copies for sale -- 15 used from \$35.54 and two new from \$1,730,045.91 (one from seller [profnath](#) at that price and a second from [bordeebook](#) at \$2,198,177.95).

This was assumed to be a mistake, but when Eisen returned to the page the next day, he noticed the price had gone up, with both copies on offer for around \$2.8 million. By the end of the day, profnath had raised its price again to \$3,536,674.57. He worked out that once a day, profnath set its price to be 0.9983 times the price of the copy offered by bordeebook (keen to undercut its competitor), meanwhile the prices of bordeebook were rising at 1.270589 times the price offered by profnath.

WATCH

Maleficent: Re-creating Fully Digital Characters

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The **May 6, 2010, flash crash**,<sup>[1][2][3]</sup> also known as the **crash of 2:45** or simply the **flash crash**, was a United States trillion-dollar<sup>[4]</sup> [stock market crash](#), which started at 2:32 p.m. [EDT](#) and lasted for approximately 36 minutes.<sup>[5]:1</sup>

Between 2:45:13 and 2:45:27, HFTs traded over 27,000 contracts, which accounted for about 49 percent of the total trading volume, while buying only about 200 additional contracts net.

# What is going wrong / can go wrong?

- Systems **insufficiently capable/intelligent**
- Systems **insufficiently aligned** with what we (really) want them to do
- **Game-theoretic issues** between multiple systems

# A(n imagined) conversation between two self- driving cars

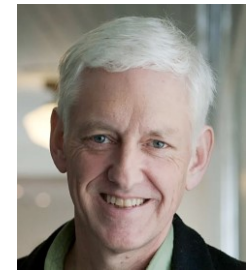
(see paper [Designing Preferences, Beliefs, and Identities for Artificial Intelligence](#))



# Russell and Norvig's "AI: A Modern Approach"



Stuart Russell



Peter Norvig

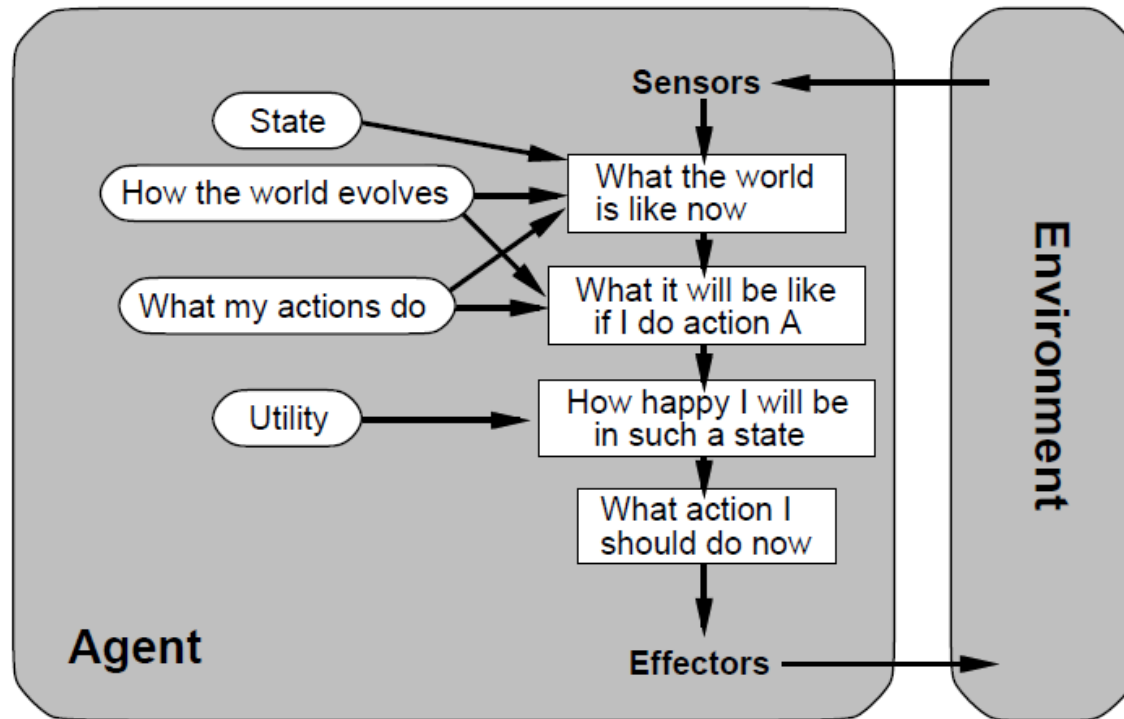
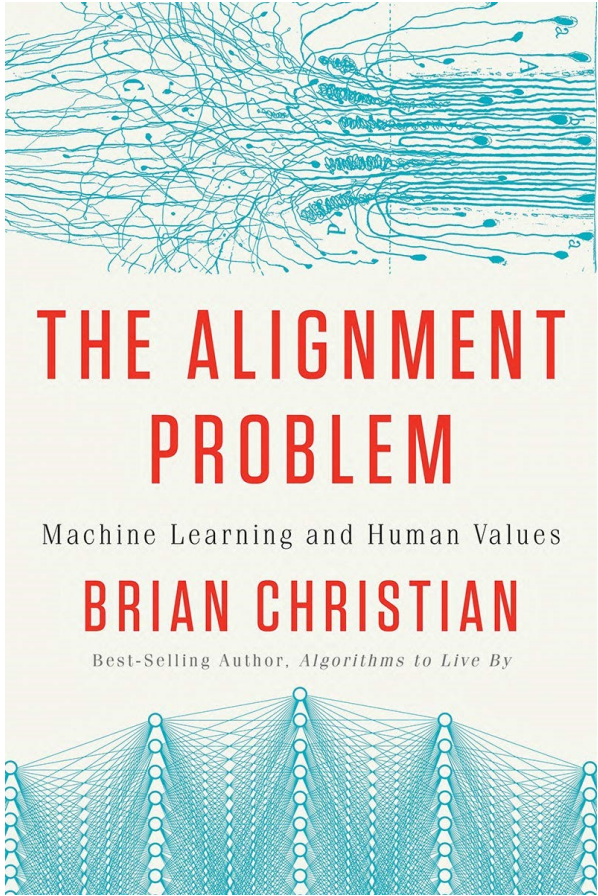
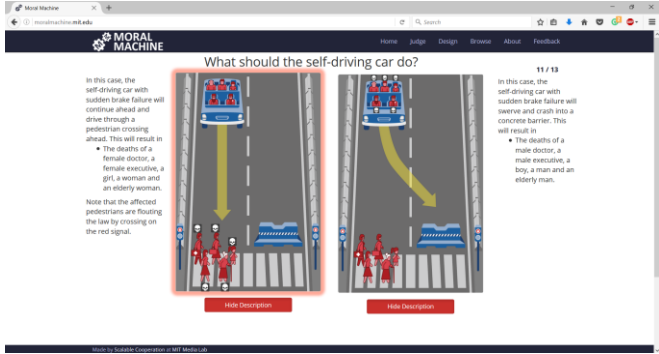
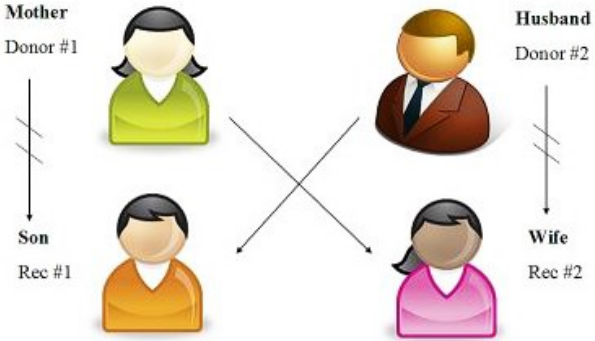


Figure 2.12 A complete utility-based agent.

“... we will insist on an objective performance measure imposed by some authority. In other words, we as outside observers establish a standard of what it means to be successful in an environment and use it to measure the performance of agents.”



# AI Alignment



Fifth AAAI /ACM Conference on  
**Artificial Intelligence,  
Ethics, and Society**  
**Oxford**  
**August 1-3, 2022**



UNIVERSITY OF OXFORD

**Institute for  
Ethics in AI**  
Oxford leading the way in AI  
ethics

Stanford University

One Hundred Year Study on Artificial  
Intelligence (AI100)

# Even almost perfectly aligned agents can perform horribly in equilibrium

- Two agents each provide part of a service, each chooses quality  $q_i$
- **Overall quality** determined by  $\min_i q_i$
- Agents care primarily about overall quality, but also have a slight incentive to be the lower one

	100	90	80	70	60	50	40	30	20	10	0
100	111, 111	90, 112	80, 102	70, 92	60, 82	50, 72	40, 62	30, 52	20, 42	10, 32	0, 22
90	112, 90	101, 101	80, 102	70, 92	60, 82	50, 72	40, 62	30, 52	20, 42	10, 32	0, 22
80	102, 80	102, 80	91, 91	70, 92	60, 82	50, 72	40, 62	30, 52	20, 42	10, 32	0, 22
70	92, 70	92, 70	92, 70	81, 81	60, 82	50, 72	40, 62	30, 52	20, 42	10, 32	0, 22
60	82, 60	82, 60	82, 60	82, 60	71, 71	50, 72	40, 62	30, 52	20, 42	10, 32	0, 22
50	72, 50	72, 50	72, 50	72, 50	72, 50	61, 61	40, 62	30, 52	20, 42	10, 32	0, 22
40	62, 40	62, 40	62, 40	62, 40	62, 40	62, 40	51, 51	30, 52	20, 42	10, 32	0, 22
30	52, 30	52, 30	52, 30	52, 30	52, 30	52, 30	52, 30	41, 41	20, 42	10, 32	0, 22
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10	32, 10	32, 10	32, 10	32, 10	32, 10	32, 10	32, 10	32, 10	32, 10	21, 21	0, 22
0	22, 0	22, 0	22, 0	22, 0	22, 0	22, 0	22, 0	22, 0	22, 0	22, 0	11, 11

*(Cf. Traveler's Dilemma)*

# Prisoner's Dilemma

- Pair of criminals has been caught
- District attorney has evidence to convict them of a minor crime (1 year in jail); knows that they committed a major crime together (3 years in jail) but cannot prove it
- Offers them a deal:
  - If both confess to the major crime, they each get a 1 year reduction
  - If only one confesses, that one gets 3 years reduction

	confess	don't confess
confess	-2, -2	0, -3
don't confess	-3, 0	-1, -1

# “Should I buy an SUV?”

purchasing + gas cost



cost: 5



cost: 3

accident cost

cost: 5



cost: 5

cost: 8



cost: 2

cost: 5




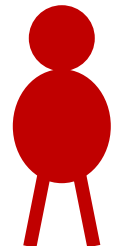
cost: 5



-10, -10	-7, -11
-11, -7	-8, -8

# Choosing a cause to support

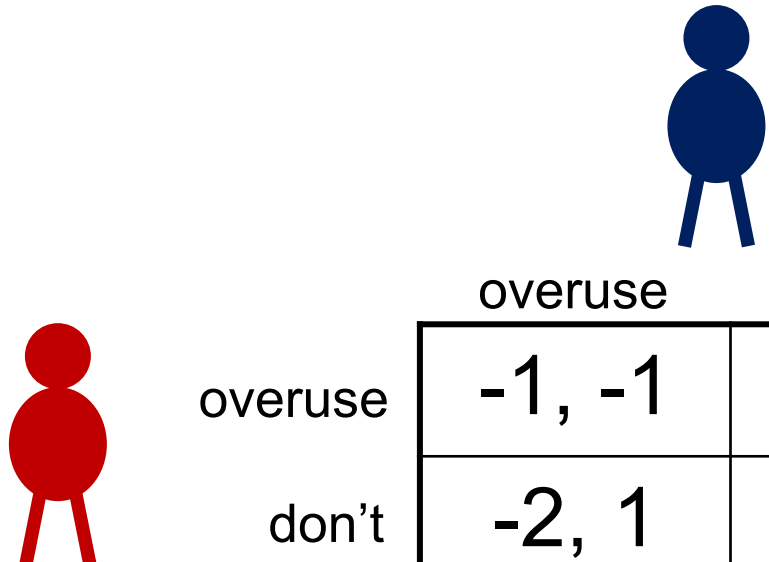
- Red agent cares about climate change (+2 if someone works on that) and about cleaning up Red Town (+3 if someone works on that)
- Blue agent cares about climate change (+2 if someone works on that) and about cleaning up Blue Town (+3 if someone works on that)



	clean BT	climate change
clean RT	3, 3	5, 2
climate change	2, 5	4, 4


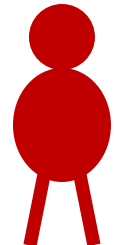
# Tragedy of the commons

- Overuse the environment (overgraze, pollute the river, ...) or don't
- The overusing agent benefits 3 from overusing, but **everyone** experiences a cost of 2 from each instance of overusing



	overuse	don't
overuse	-1, -1	1, -2
don't	-2, 1	0, 0

# Prisoner's Dilemma



	cooperate	defect
cooperate	2, 2	0, 3
defect	3, 0	1, 1

Should AI systems cooperate like humans do?



Science

HOME > NEWS > ALL NEWS > HUMAN ALTRUISM TRACES BACK TO THE ORIGINS OF HUMANITY

NEWS | BRAIN & BEHAVIOR

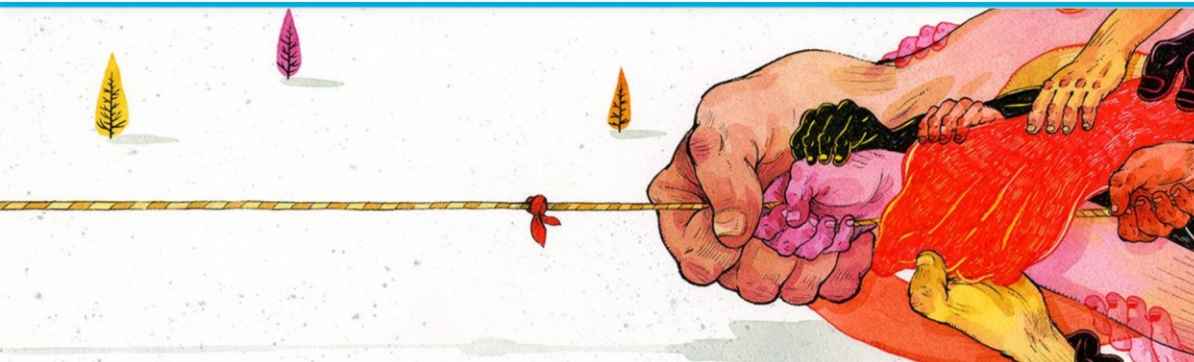
# Human altruism traces back to the origins of humanity

Study probes why humans are more cooperative than other animals

27 AUG 2014 • BY [MICHAEL BALTER](#)

NAUTILUS

ISSUES TOPICS CORONAVIRUS BLOG NEWSLETTER f t LOGIN SUBSCRIBE



BIOLOGY | PSYCHOLOGY

## Cooperation Is What Makes Us Human

*Where we part ways with our ape cousins.*

BY KAT MCGOWAN  
ILLUSTRATIONS BY JOHN HENDRIX  
APRIL 29, 2013

[Philos Trans R Soc Lond B Biol Sci](#). 2010 Sep 12; 365(1553): 2663–2674. PMID: [20679110](#)  
doi: [10.1098/rstb.2010.0157](#)

Philos Trans R Soc Lond B Biol Sci

### How is human cooperation different?

[Alicia P. Melis](#)<sup>1,\*</sup> and [Dirk Semmann](#)<sup>2,\*</sup>

▶ [Author information](#) ▶ [Copyright and License information](#) [Disclaimer](#)

This article has been [cited by](#) other articles in PMC.

**ABSTRACT** [Go to:](#)

Although cooperation is a widespread phenomenon in nature, human cooperation exceeds that of all other species with regard to the scale and range of cooperative activities. Here we review and

## Why We're So Nice: We're Wired to Cooperate



By [Natalie Angier](#)

July 23, 2002

# When the System Fails

COVID-19 and the Costs of Global Dysfunction

By Stewart Patrick July/August 2020



Heads of State

The chaotic global response to the coronavirus pandemic has tested the faith of even the most ardent internationalists. Most nations, including the world's most powerful, have turned inward, adopting travel bans, implementing export controls, hoarding or obscuring



## Why International Cooperation is Failing

How the Clash of Capitalisms Undermines the Regulation of Finance

Thomas Kalinowski

- Provides a new alternative to liberal and realist mainstream theories of International Political Economy
- Extends research in Comparative and International Political Economy beyond eurocentrism and nation state focus to studies of East Asian and euro capitalism
- Provides a new methodological approach to International Studies by combining International Political Economy and Comparative Capitalism



## WHY COOPERATION FAILED IN 1914

By STEPHEN VAN EVERA\*

THE essays in this volume explore how three sets of factors affect the degree of cooperation or non-cooperation between states. The first set comprises the “structures of payoffs” that states receive in return for adopting cooperative or noncooperative policies; payoff structures are signified by the rewards and penalties accruing to each state from mutual cooperation (CC); cooperation by one state and “defection” by another (CD and DC); and mutual defection (DD). The second set comprises the “strategic setting” of the international “game”—that is, the rules and conditions under which international relations are conducted. Two aspects of the strategic setting are considered: the size of the “shadow of the future,” and the ability of the players to “recognize” past cooperators and defectors, and to distinguish between them.<sup>1</sup> The third set is the number of players in the game, and the influence these

## The Global Climate Talks Ended In Disappointment

One activist group pronounced the conclusions a “pile of shite” and dumped manure outside the meeting hall.



Zahra Hirji  
BuzzFeed News Reporter



J. Lester Feder  
BuzzFeed News Reporter

Posted on December 15, 2019, at 10:29 a.m. ET

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# Some (highly interdisciplinary) discussion points: Should we make AI more human-like?

- Should we make our agents have **prosocial inclinations**? **Ethics**?
  - Genuine solution vs. wishful thinking?
  - What about **norms** and **rules**?
- Do certain human **cognitive limitations** limit tragedies? Should/can we replicate that in AI agents?
  - Traveler's dilemma and behavioral game theory
  - *Any fool can tell the truth, but it requires a man of some sense to know how to lie well.* -- Samuel Butler
- Might AI **do better** on cooperation than humans? On its own? With some deliberate design decisions?

# Improving issues already found in the world today

- Problems of **collective action**
  - Climate change and other environmental problems
  - Nuclear disarmament and preventing wars
  - Agreeing on causes to support
  - ...
- Making **better decisions** in contexts with strategic aspects
  - Allocating scarce resources
    - Kidney exchange, combinatorial auctions
  - Predicting the future
    - Prediction markets
  - Collective deliberation
  - ...

# Why, technically, is AI useful in addressing these problems?

- Dealing with **combinatorial explosions** in incentive-minded way
  - Combinatorial auctions, kidney exchanges, expressive donations
- Efficiently **learning / eliciting important information** from the world such as preferences / values
  - Again above topics
- Taking advantage of **rich data**
  - Automated mechanism design takes advantage of knowledge about distribution of preferences
- **Monitoring, transparency, openness**
  - Nuclear test monitoring, emissions monitoring, ...
- Enabling **simulation** of complex environments
  - E.g., climate change competition (next)
- Introduction of **mediators** and other strategic entities to **strategically steer to better outcomes**
- ...

# Can you design climate agreements and negotiation protocols that lead to a sustainable future?



Join our working group collaboration and this competition to model and foster global cooperation on climate change.

Collaborate with computer scientists, economists, climate scientists, behavioral scientists, legal, ethics, and policy experts.

[Get started and learn more](#)

[Register yourself to get involved!](#)

## We need global cooperation on climate change

Climate change is happening fast. The latest [IPCC report](#) warns that it is **'now or never'** if the world is to stave off climate disaster. However, it is still [a race we can win](#), capping the global temperature increase at 2 degrees Celsius.

To mitigate climate change, we need comprehensive long-term global cooperation. This poses a complex game-theoretic problem. There is no central entity that forces regions to adhere to climate agreements, while regions have individual policy objectives that are often misaligned.

## Will your solutions lead to better climate outcomes?

Design multilateral negotiation protocols and agreements that incentivize cooperation on climate change.

Test your solutions in RICE-N: a climate-economic simulation with AI agents that has been calibrated to real-world data.

## Prescription AI

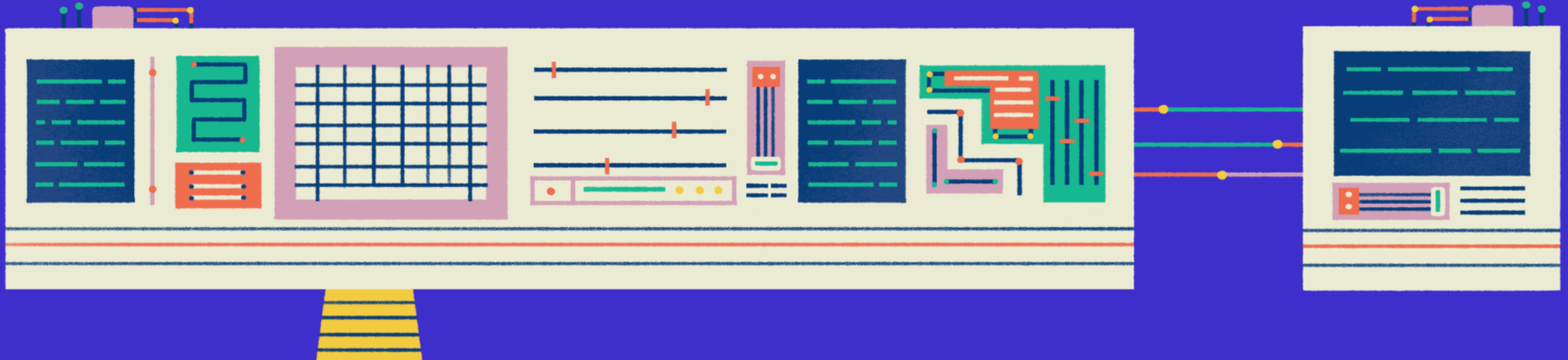
This series explores the promise of AI to personalize, democratize, and advance medicine—and the dangers of letting machines make decisions.

THE BOTPERATING TABLE

# How AI changed organ donation in the US

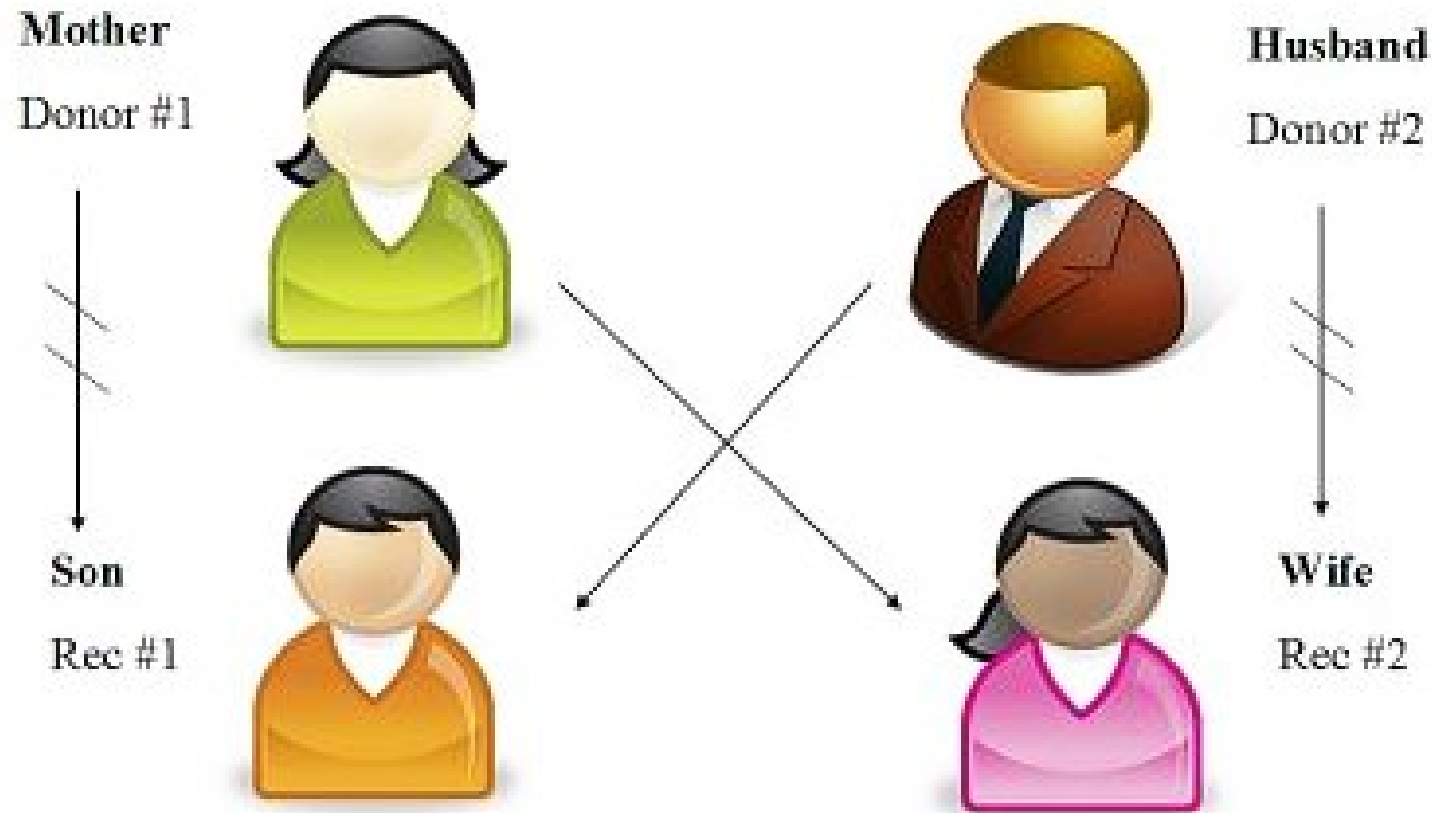
(thanks to Tuomas and his group)

By [Corinne Purtill](#) · September 10, 2018



# Kidney exchange [\[Roth, Sönmez, and Ünver 2004\]](#)

- Kidney exchanges allow patients with willing but incompatible live donors to swap donors





# Cooperative AI Foundation seminar series

New Directions in Cooperative AI

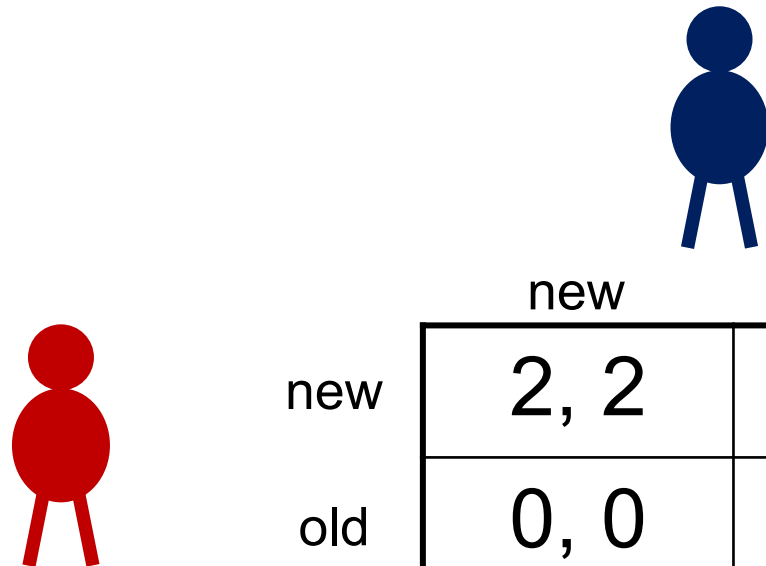
Date	Seminar Title	Speakers
15:00-16:30 UTC 19 May 2022	<b>Collective Cooperative Intelligence</b>	Wolfram Barfuss (University of Tübingen, Princeton University)
16:00-17:30 UTC 6 May 2022	<b>The Foundations of Cooperative Intelligence</b>	Gillian Hadfield (Schwartz Reisman Institute for Technology and Society, University of Toronto)
16:00-17:30 UTC 28 April 2022	<b>What Makes Human Data Special? How to Learn from Humans, Teach Them, and Help Them Better Teach Us</b>	Dorsa Sadigh (Stanford University)
15:00-16:30 UTC 22 April 2022	<b>Cultural Evolution as a Cooperative AI Generating Algorithm</b>	Edward Hughes (DeepMind)
13:00-14:00 UTC 10 March 2022	<b>Differential Progress in Cooperative AI: Motivation and Measurement</b>	Jesse Clifton (Center on Long-Term Risk, CAIF, NCSU) Sammy Martin (KCL, Center on Long-Term Risk)
15:00-16:00 UTC 17 February 2022	<b>How to Measure and Train the Social-Cognitive Capacities, Representations, and Motivations Underlying Cooperation</b>	Joel Leibo (DeepMind)
15:00-16:00 UTC 20 January 2022	<b>AI Agents May Cooperate Better if They Don't Resemble Us</b>	Vincent Conitzer (Duke University, University of Oxford)

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- **Quickly touching on all kinds of topics in the course!**
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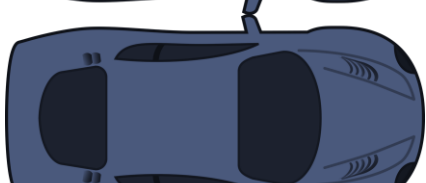
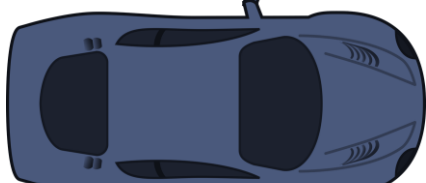
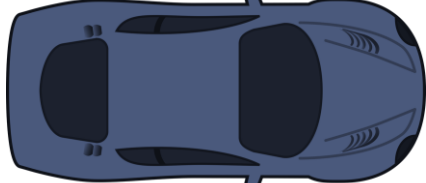
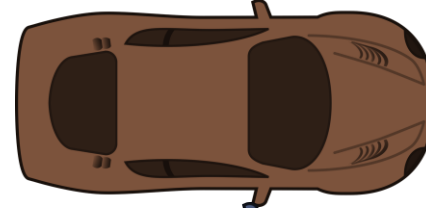
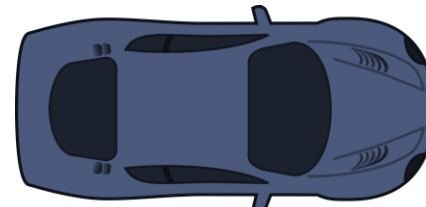
# Equilibrium multiplicity and selection

- A better new technology is introduced, but it's most important to have the same technology as your friend



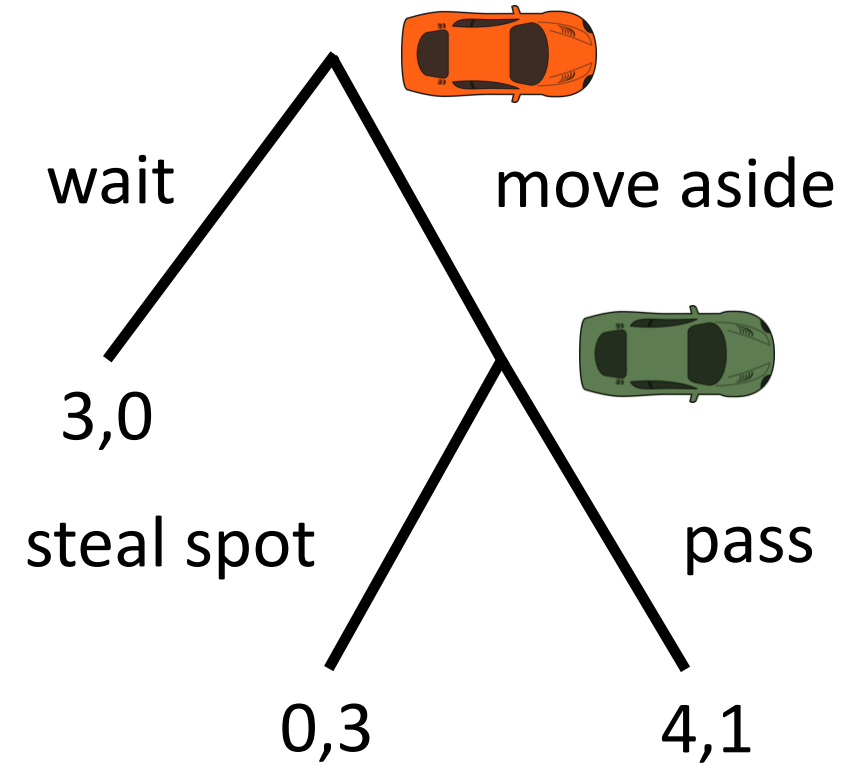
	new	old
new	2, 2	0, 0
old	0, 0	1, 1

- How do we compute / learn / move over to the better equilibrium?
- How do we avoid miscoordination?
- *Keep in mind throughout the course*



# THE PARKING GAME

(cf. the trust game [\[Berg et al. 1995\]](#))



[\[Letchford, C., Jain 2008\]](#)

define a solution concept capturing this

# Infinitely Repeated Prisoner's Dilemma

	cooperate	defect
cooperate	2, 2	0, 3
defect	3, 0	1, 1

$t=0$

→

	cooperate	defect
cooperate	2, 2	0, 3
defect	3, 0	1, 1

$t=1$

→ ...

- **Grim trigger** strategy: cooperate as long as everyone cooperates; after that, defect forever. (Equilibrium, if players are somewhat patient.)
- *Folk theorem*: with sufficiently patient players, can always sustain cooperation this way, in any game.
- Folk theorem can be used to efficiently compute equilibria (in infinitely repeated games with sufficiently patient players) [[Littman & Stone DSS 2005](#), [Andersen & C., AAI'13](#)]

# Repeated games on social networks

[\[Moon & C., IJCAI'15\]](#)

- **Common assumption:** an agent's behavior is instantly observable to all other agents (instant punishment)
- What if there is a delay in knowledge propagation due to network structure?

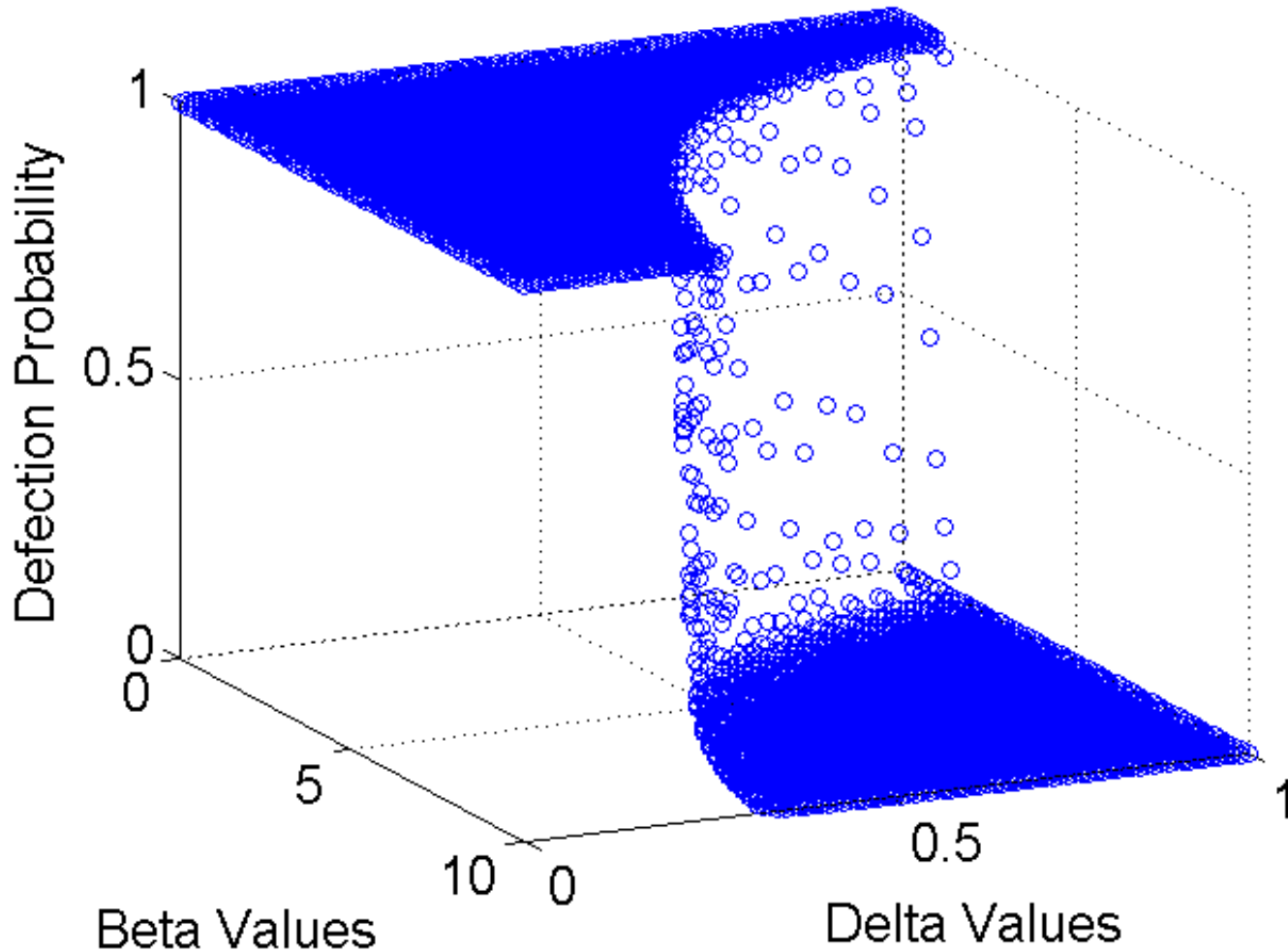


Catherine  
Moon



- **Algorithm** for finding (**unique**) maximal set of cooperating agents

# Experiments on random graphs: Phase transition between complete cooperation and complete defection



## Random graph models:

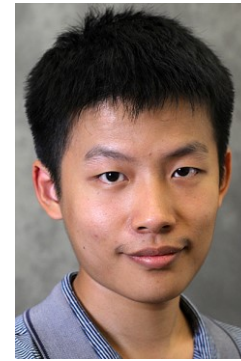
Erdős–Rényi (ER)

Barabási–Albert preferential-attachment (PA)

Beta = cooperation benefit, delta = discount factor

# Disarmament Game

[\[Deng & C., AAI'17, '18\]](#)



Yuan Deng

	GR	KR	ST
R	10, -5	0, -4	0, -4
PF	4, 1	-10, 3	-0.5, -0.5
PD	-6, 8	-10, 3	-0.5, -0.5



# Disarmament Game

	GR	KR	ST
R	10, -5	0, -4	0, -4
PF	4, 1	-10, 3	-0.5, -0.5
PD	-6, 8	-5, 3	-0.5, -0.5

Pure Nash equilibria

Pure Stackelberg equilibria (no matter who takes the lead)

# Disarmament Game

	GR	KR	ST
R	10, -5	0, -4	0, -4
PF	4, 1	-10, 3	-0.5, -0.5
PD	-6, 8	-10, 3	-0.5, -0.5

**Desired Outcome**

Pareto better than the Nash equilibrium outcome

# Multiple-round (pure) commitments

	GR	KR	ST
R	10, -5	0, -4	0, -4
PF	4, 1	-10, 3	-0.5, -0.5
PD	-6, 8	-10, 3	-0.5, -0.5

# Multiple-round (pure) commitments

	<b>GR</b>		<b>ST</b>
<b>R</b>	10, -5		0, -4
<b>PF</b>	4, 1		-0.5, -0.5
<b>PD</b>	-6, 8		-0.5, -0.5

# Multiple-round (pure) commitments

	GR		ST
R	10, -5		0, -4
PF	4, 1		-0.5, -0.5
PD	-6, 8		-0.5, -0.5



Incentivize Row to commit in the next round

# Multiple-round (pure) commitments

	<b>GR</b>		<b>ST</b>
<b>R</b>	10, -5		0, -4
<b>PF</b>	4, 1		-0.5, -0.5
<b>PD</b>	-6, 8		-0.5, -0.5

# Multiple-round (pure) commitments

	GR		ST
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# Multiple-round (pure) commitments

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PF	4, 1	-10, 3	-0.5, -0.5
PD	-6, 8	-10, 3	-0.5, -0.5

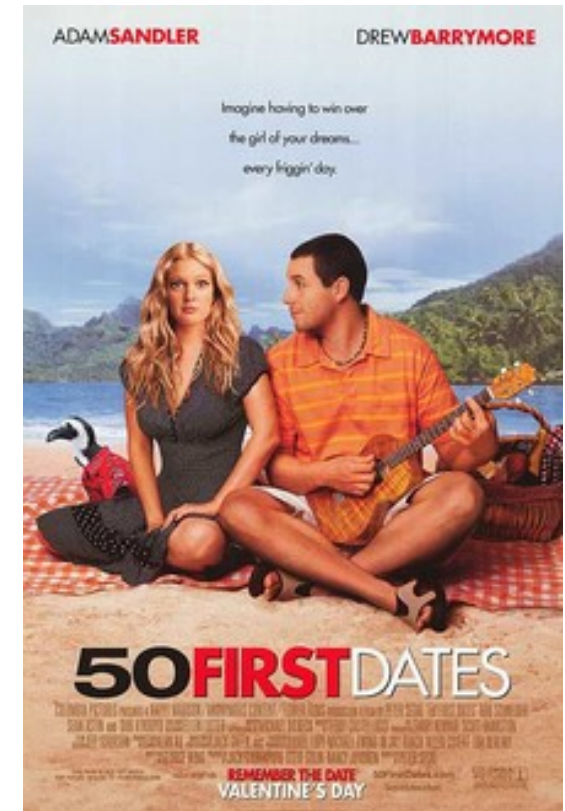
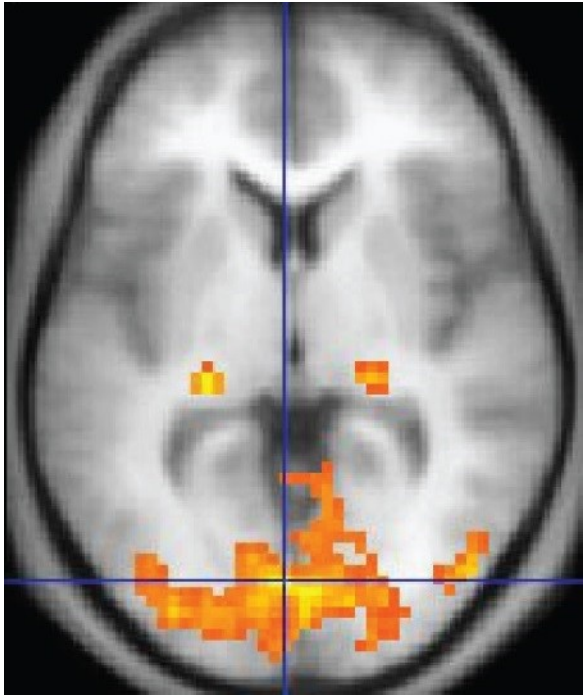


**Fact:** The desired outcome **cannot be achieved** if Row commits first  
In general, it is an **NP-hard problem** to determine whether an outcome can be reached without creating incentive to deviate from disarmament

AI agents can be unlike us...

# What should you do if...

- ... you knew *others could read your code?*
- ... you knew *you were facing someone running the same code?*
- ... you knew *you had been in the same situation before but can't possibly remember what you did?*



# Program equilibrium [[Tennenholtz 2004](#)]

- Make your own code legible to the other player's program!

```
If (other's code = my code)
    Cooperate
Else
    Defect
```



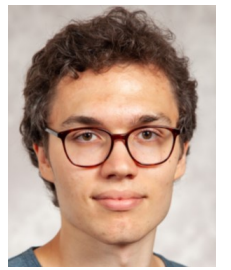
```
If (other's code = my code)
    Cooperate
Else
    Defect
```



	cooperate	defect
cooperate	2, 2	0, 3
defect	3, 0	1, 1

- See also: [[Fortnow 2009](#), [Kalai et al. 2010](#), [Barasz et al. 2014](#), [Critch 2016](#), [Oesterheld 2018](#), ...]

# Robust program equilibrium [[Oesterheld 2018](#)]



Caspar Oesterheld

- Can we make the equilibrium less fragile?

With probability  $\varepsilon$   
Cooperate  
Else  
Do what the other  
program does against  
this program



	cooperate	defect
cooperate	2, 2	0, 3
defect	3, 0	1, 1

...

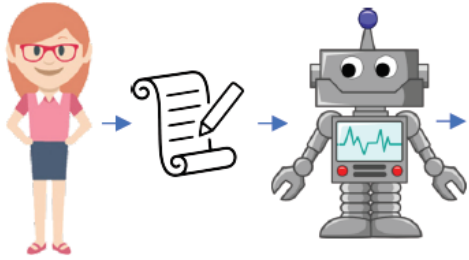
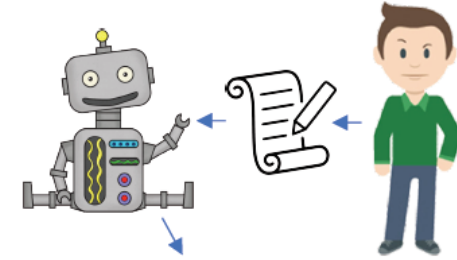
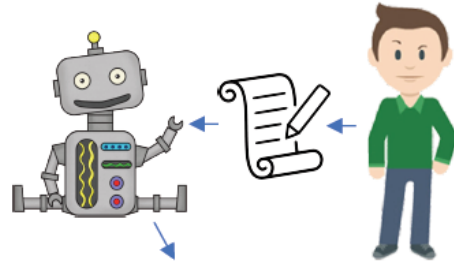


# Safe Pareto improvements for delegated game playing [\[AAMAS'21\]](#), with

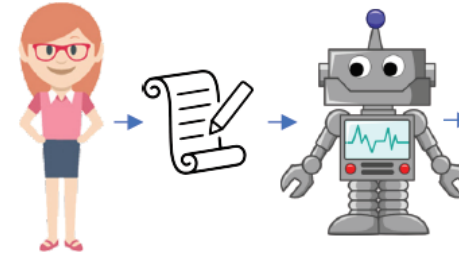


Caspar Oesterheld

Delegated game playing



	DM	RM	DL	RL
DM	-5,-5	2,0	5,-5	5,-5
RM	0,2	1,1	5,-5	5,-5
DL	-5,5	-5,5	1,1	2,0
RL	-5,5	-5,5	0,2	1,1

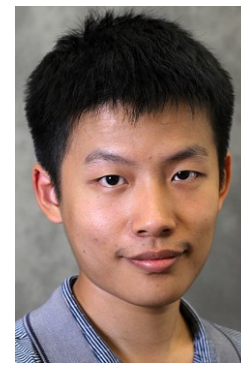


	DL	RL
DL	-5,-5 (1,1)	2,0 (2,0)
RL	0,2 (0,2)	1,1 (1,1)

- Representatives are competent at playing games and the original players trust the representatives.  
=> **Default: aligned delegation**
- DL,RL are strictly dominated and therefore never played
- **Equilibrium selection problem**  
=> Pareto-suboptimal outcome (DM,DM) might occur

- Each player's contract says: Play this alternative game if the other player adopts an analogous contract.
- The games are essentially isomorphic.
  - $DM \sim DL$
  - $RM \sim RL$
- *Safe Pareto improvement* on the original game: outcome of new game is better for both players with certainty.

# Disarmament revisited: Committing to your first few lines of code



Yuan Deng

1. With probability  
40%, cooperate  
3. With probability  
40%, cooperate  
...



cooperate  
defect

	cooperate	defect
cooperate	2, 2	0, 3
defect	3, 0	1, 1

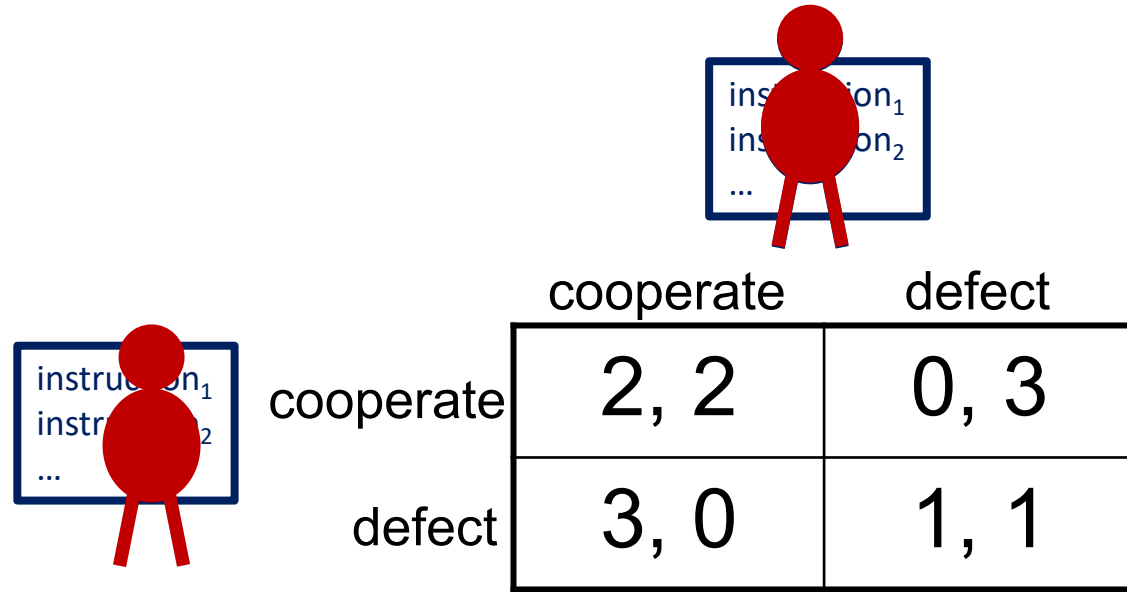


2. With probability  
40%, cooperate  
4. With probability  
40%, cooperate  
...

- E.g., if Blue refuses to add line 2, then Red defects with probability .6, resulting in at most  $.4*3 + .6*1 = 1.8$  for Blue
- “Folk theorem” [Deng & C., AAI’17, ‘18] that cooperation can always be achieved this way!



# Prisoner's Dilemma against (possibly) a copy



		cooperate	defect
cooperate		2, 2	0, 3
defect		3, 0	1, 1

- What if you play against your twin that you always agree with?
- What if you play against your twin that you *almost* always agree with?

related to working paper  
[\[Oesterheld, Demski, C.\]](#)



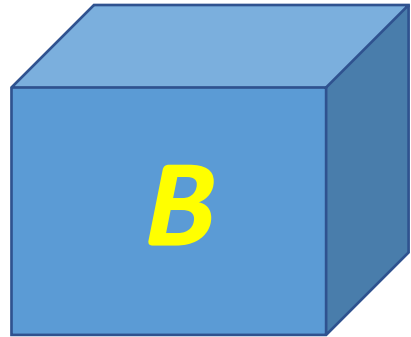
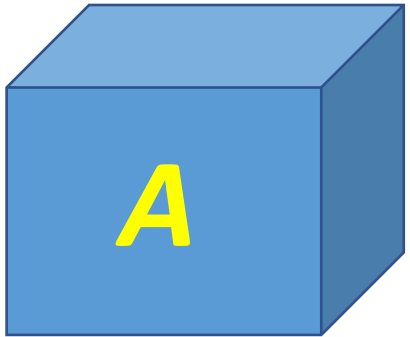
Caspar Oesterheld



Abram Demski

# Newcomb's Demon

- Demon earlier put positive amount of money in each of two boxes
- Your choice now: (I) get contents of Box B, or (II) get content of **both** boxes (!)
- Twist: demon first **predicted** what you would do, is uncannily accurate
- If demon predicted you'd take just B, there's \$1,000,000 in B (and \$1,000 in A)
- Otherwise, there's \$1,000 in each
- What would **you** do?



# The lockdown dilemma

- Lockdown is **monotonous**: you forget what happened before, you forget what day it is
- Suppose you know lockdown lasts two days (unrealistic)
- Every morning, you can decide to eat an unhealthy cookie! (or not)
- Eating a cookie will give you +1 utility immediately, but then -3 later the *next* day
- **But, *carpe diem*: you only care about today**
- Should you eat the cookie right now?



related to working paper [\[C.\]](#)

# Your own choice is **evidence**...

- ... for what the demon put in the boxes
- ... for whether your twin defects
- ... for whether you eat the cookie on the other day



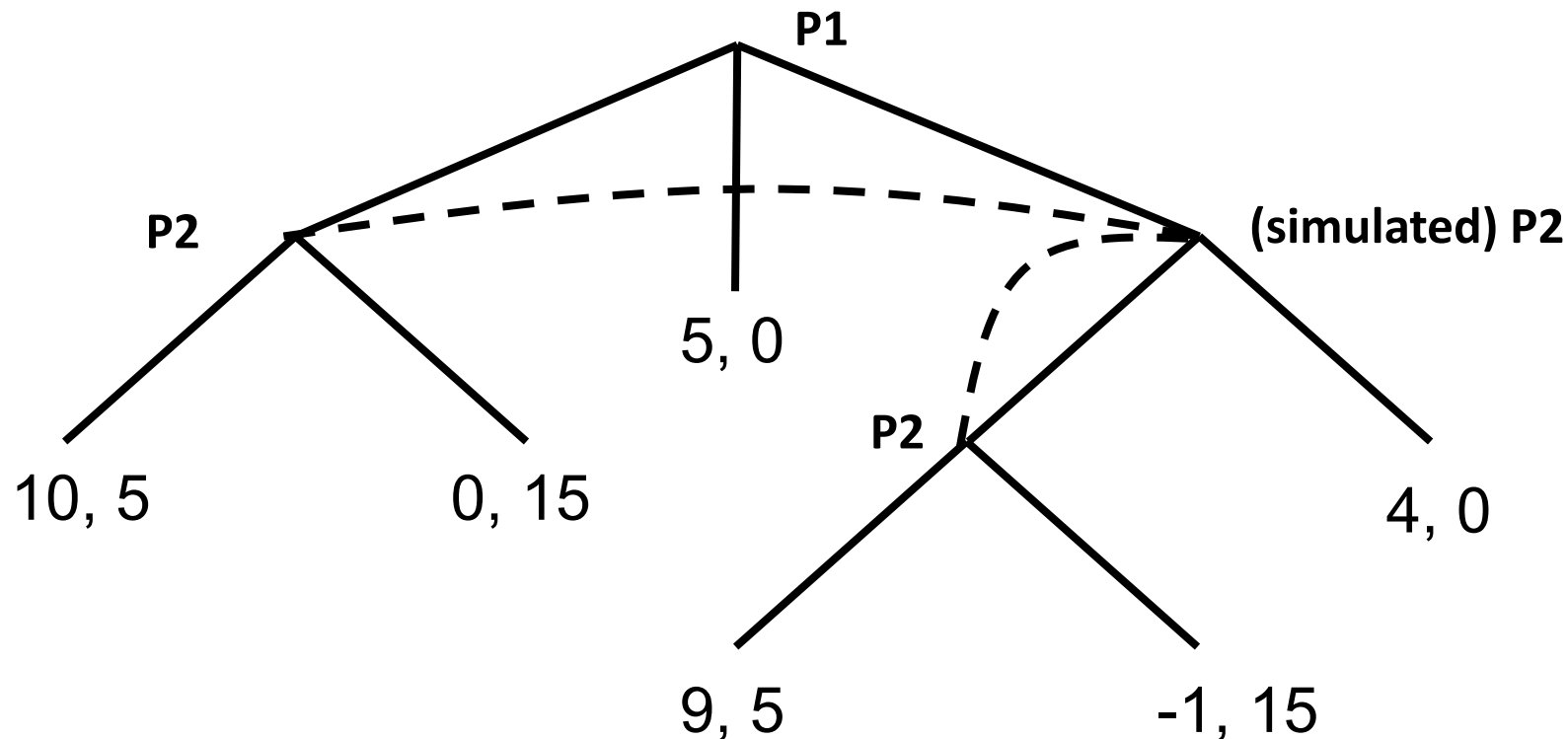
	cooperate	defect
cooperate	2, 2	0, 3
defect	3, 0	1, 1



- *Evidential Decision Theory (EDT)*: When considering how to make a decision, consider **how happy you expect to be conditional on taking each option** and choose an option that maximizes that
- *Causal Decision Theory (CDT)*: Your decision should focus on what you **causally affect**

# Simulating our way to cooperation?

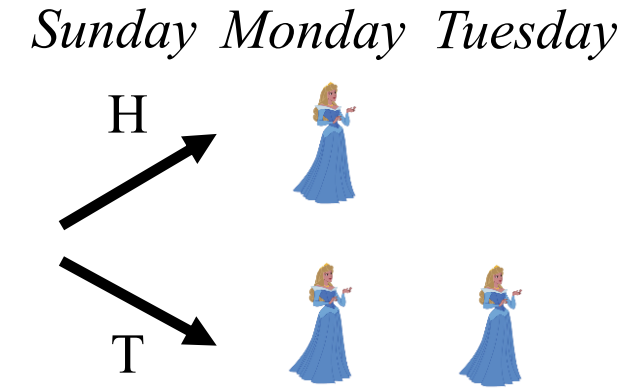
- Restricted trust game: P1 can give 5 which would be tripled, or 0; after receiving 15, P2 can give back 10, or 0
- Twist: P1 can *simulate* P2 first, at a cost of 1



As (AI system) P2, how likely is it you're now running as a simulation? → *self-locating belief*  
What happens in equilibrium?

# The Sleeping Beauty problem [\[Elga'00\]](#)

- There is a participant in a study (call her Sleeping Beauty)
- On Sunday, she is given drugs to fall asleep
- A coin is tossed (H or T)
- If H, she is awoken on Monday, then made to sleep again
- If T, she is awoken Monday, made to sleep again, then **again** awoken on Tuesday
- Due to drugs she **cannot remember what day it is or whether she has already been awoken once**, but she remembers all the rules
- Imagine **you** are SB and you've just been awoken. What is your (subjective) probability that the coin came up H?



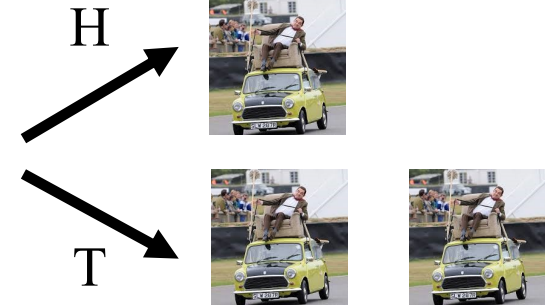
*don't do this at home / without IRB approval...*

Ties to many philosophical questions in metaphysics, philosophy of mind, ... (see references in paper)

# Modern version

- **Low-level autonomy** cars with AI that intervenes when driver makes major error
- Does not keep record of such event
- Two types of drivers: Good (1 major error), Bad (2 major errors)
- Upon intervening, what probability should the AI system assign to the driver being good?
- (Similarly: half of households install a given AI system on two devices – with what probability does the AI system think it is alone? And what about simulation case from before?)

*Sunday Monday Tuesday*



# Mechanism design (auctions)

What could go wrong?



$v(\text{painting}) = 4$



$v(\text{painting}) = 5$



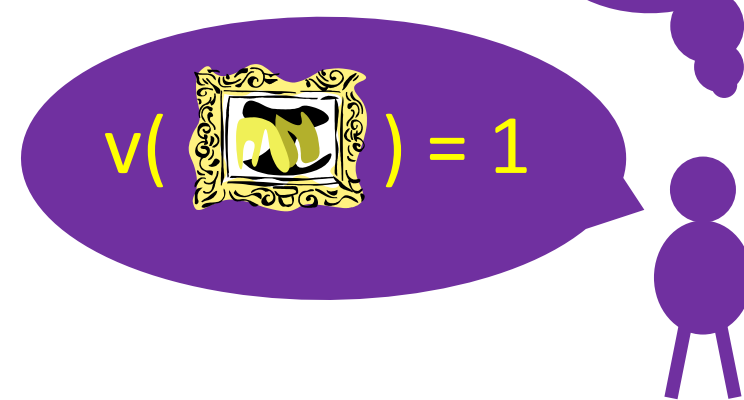
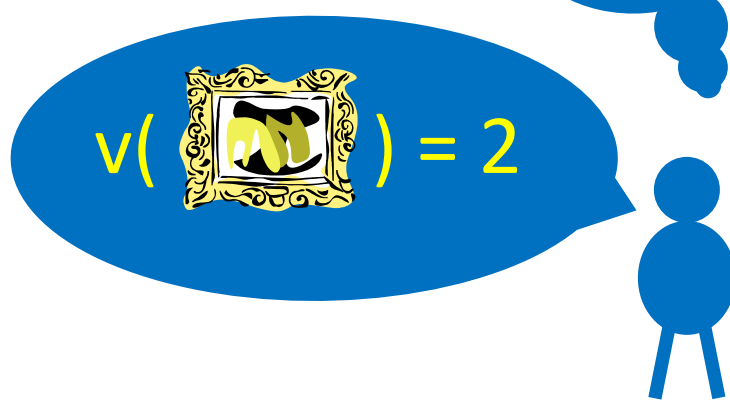
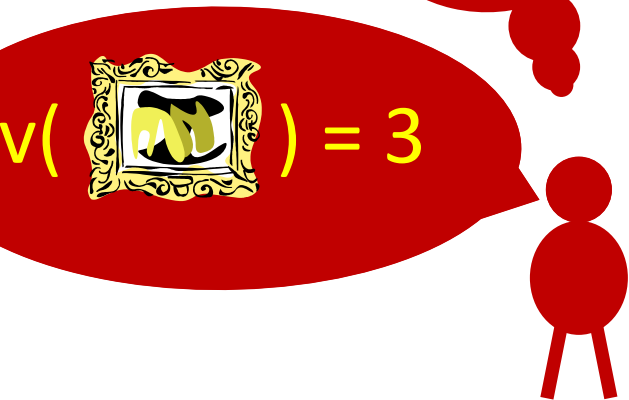
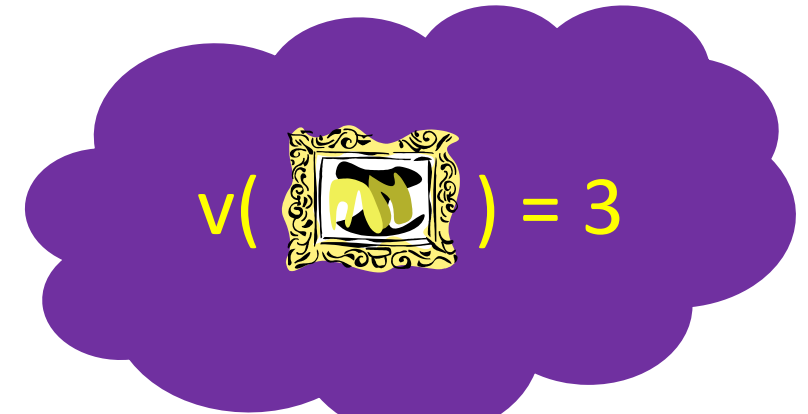
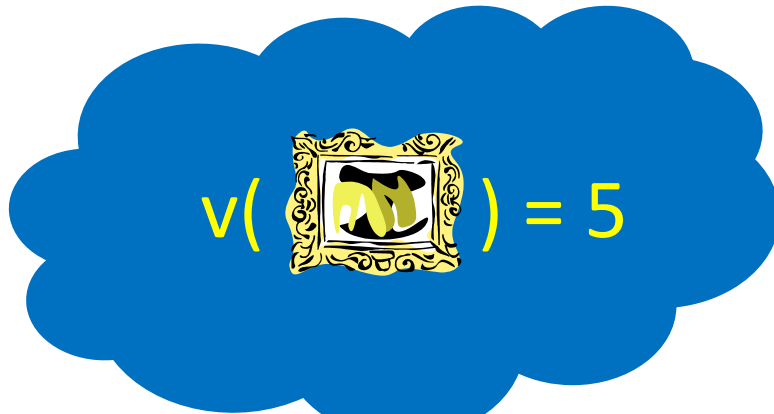
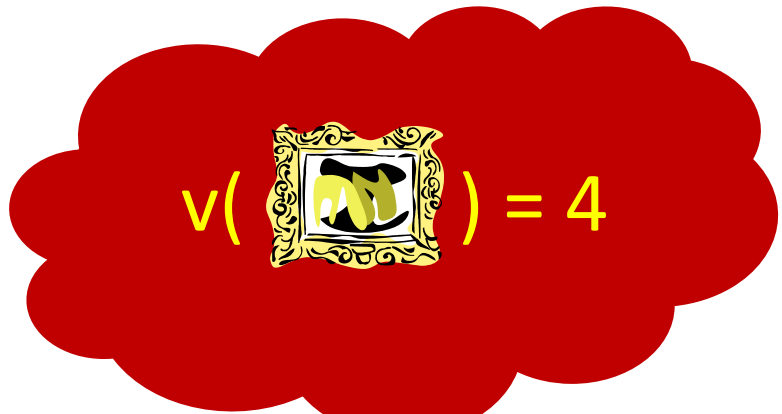
$v(\text{painting}) = 3$





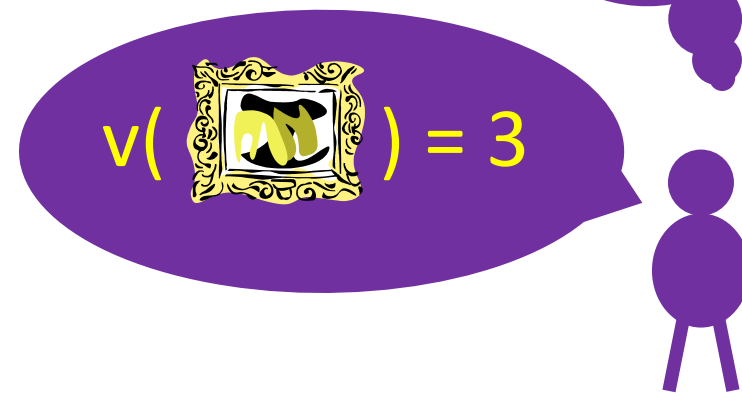
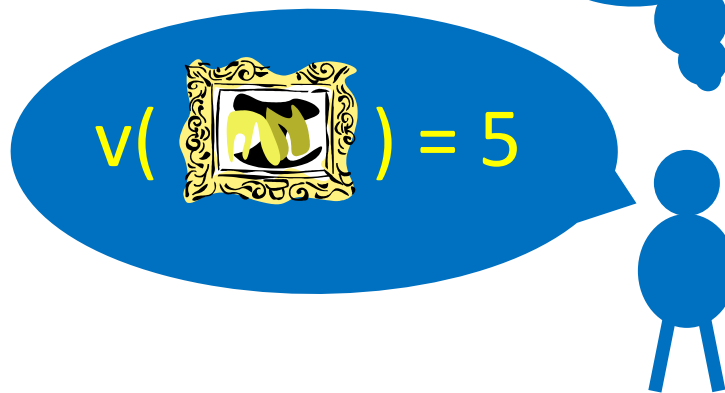
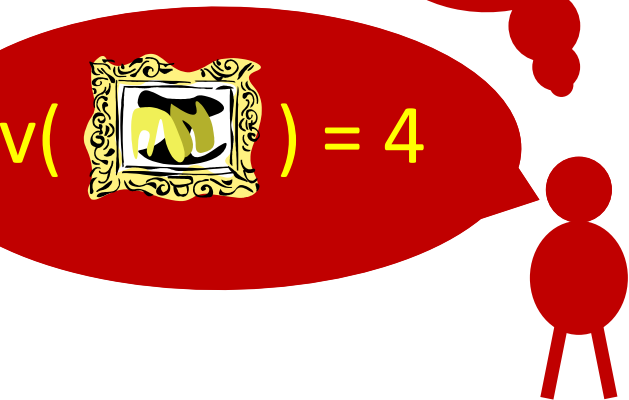
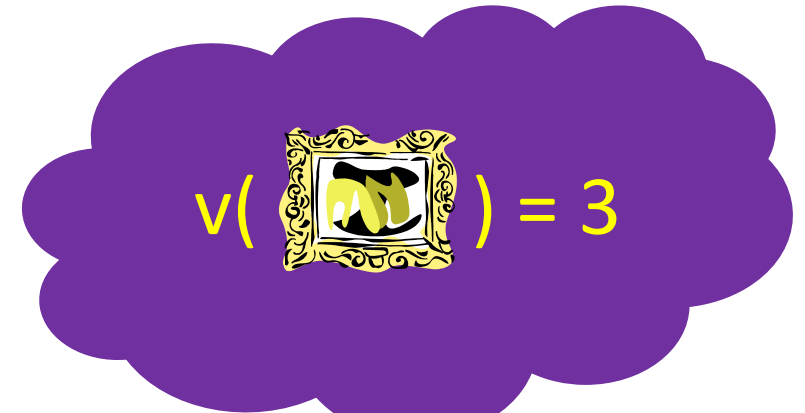
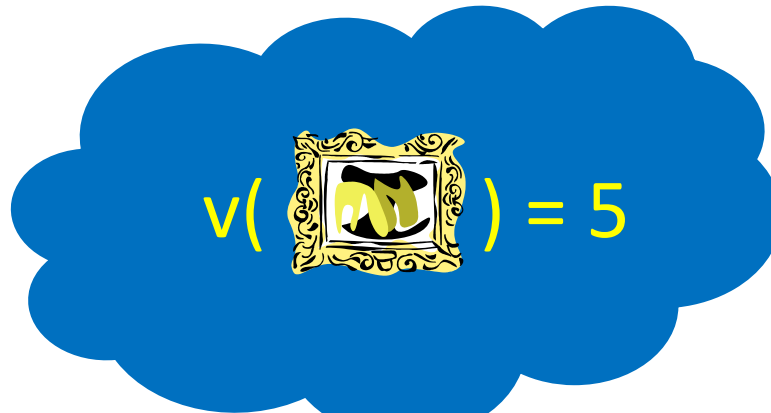
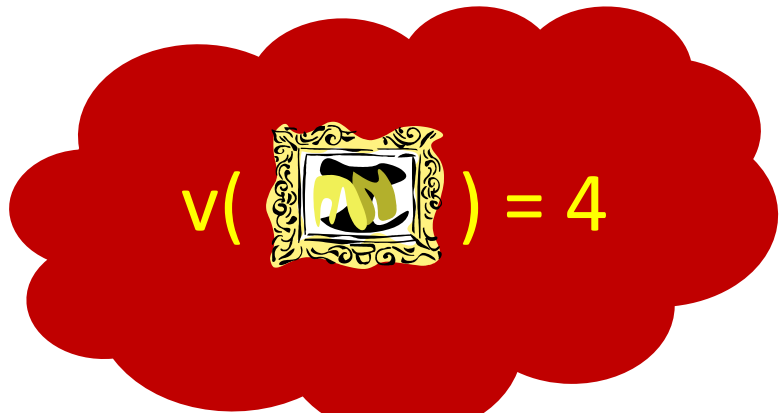
# Mechanism design (auctions)

First-price auction: highest wins, pays bid



# Mechanism design (auctions)

Second-price auction: highest wins, pays *next-highest* bid → **truthful**

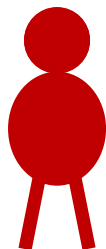
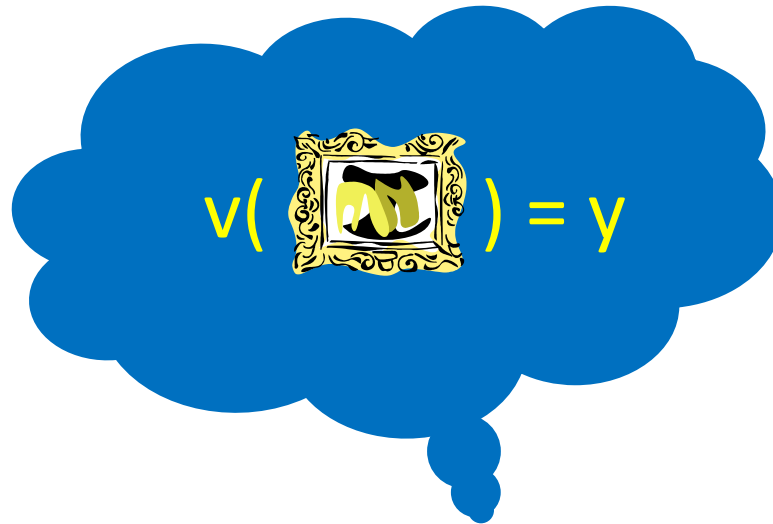
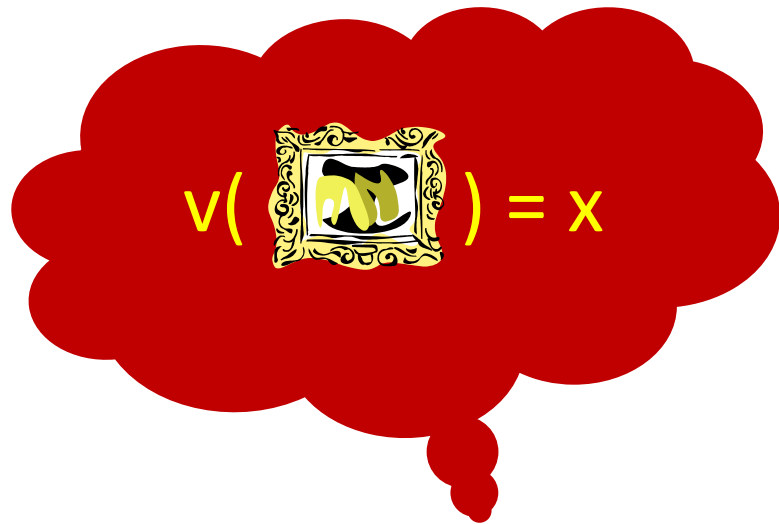


# What **else** could go wrong?

- No money
- Money doesn't track valuation
- No seller
  - Who should get the money? *Redistribution mechanisms*
- I don't even *know* my valuation!
  - *Interdependent valuations*
- Collusion
- Externalities
  - I really don't want my competitor to win!
- *Combinatorial* valuations: How much I want one item depends on whether I get another
  - *Combinatorial auctions*
- Objective: Maybe seller wants to maximize revenue, not bidder welfare
  - *Myerson auction*
  - ... but that does not allocate efficiently (e.g., reserve prices)
- Seller with a valuation, two-sided private information (next slide)
- ...

# Myerson-Satterthwaite impossibility

Seller may have a valuation, maybe the item should just stay with seller – but only seller knows valuation



seller



buyer

We would like a mechanism that:

1. is efficient (trade if and only if  $y > x$ ),
2. is budget-balanced (seller receives what buyer pays, or at least doesn't require external subsidy),
3. has voluntary participation,
4. has all this *in equilibrium*

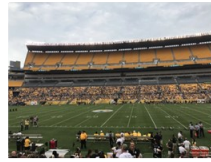
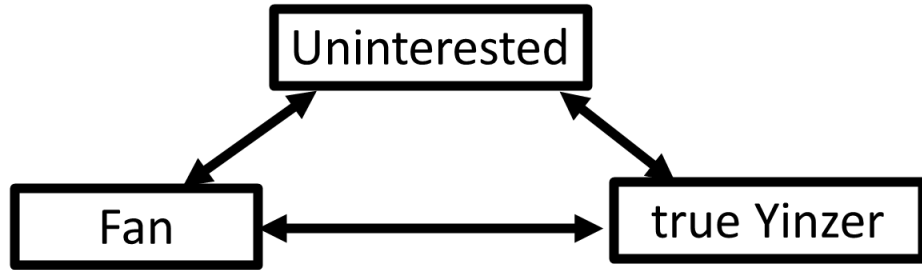
This is impossible!

# Automated

# mechanism design

[C. & Sandholm '02]

Selling tickets to a Steelers game



Great



Decent

from rateyourseats.com



- Three allocations: Great seat, Decent seat, No seat
- $v_U(G)=v_U(D)=v_U(N)=0$
- $v_F(G)=200, v_F(D)=100, v_F(N)=0$
- $v_Y(G)=500, v_Y(D)=200, v_Y(N)=0$

- A mechanism:
- U gets N, pays 0
- F gets D, pays 50
- Y gets G, pays 300

Fan pays 100      Yinzer pays 400

```
CPLEX> dis sol var -
Variable Name      Solution Value
pi_2_1             100.000000
pi_3_1             400.000000
p_t_1_o3           1.000000
p_t_2_o2           1.000000
p_t_3_o1           1.000000
All other variables in the range 1-12 are 0.
```

Yinzer gets Great seat      Fan gets Decent seat      Uninterested gets No seat

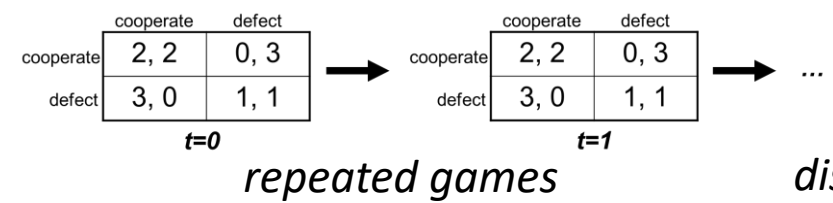
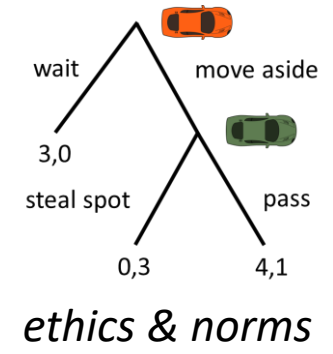
```
maximize
0.3pi_1_1 + 0.4pi_2_1 + 0.3pi_3_1
subject to
p_t_1_o1 + p_t_1_o2 + p_t_1_o3 = 1
p_t_2_o1 + p_t_2_o2 + p_t_2_o3 = 1
p_t_3_o1 + p_t_3_o2 + p_t_3_o3 = 1
0p_t_1_o1 + 0p_t_1_o2 + 0p_t_1_o3 - pi_1_1 >= 0
200p_t_2_o1 + 100p_t_2_o2 + 0p_t_2_o3 - pi_2_1 >= 0
500p_t_3_o1 + 200p_t_3_o2 + 0p_t_3_o3 - pi_3_1 >= 0
0p_t_1_o1 + 0p_t_1_o2 + 0p_t_1_o3 - pi_1_1 - 0p_t_2_o1 - 0p_t_2_o2 -
0p_t_2_o3 +
pi_2_1 >= 0
0p_t_1_o1 + 0p_t_1_o2 + 0p_t_1_o3 - pi_1_1 - 0p_t_3_o1 - 0p_t_3_o2 -
0p_t_3_o3 +
pi_3_1 >= 0
200p_t_2_o1 + 100p_t_2_o2 + 0p_t_2_o3 - pi_2_1 - 200p_t_1_o1 -
100p_t_1_o2 - 0p_
t_1_o3 + pi_1_1 >= 0
200p_t_2_o1 + 100p_t_2_o2 + 0p_t_2_o3 - pi_2_1 - 200p_t_3_o1 -
100p_t_3_o2 - 0p_
t_3_o3 + pi_3_1 >= 0
500p_t_3_o1 + 200p_t_3_o2 + 0p_t_3_o3 - pi_3_1 - 500p_t_1_o1 -
200p_t_1_o2 - 0p_
t_1_o3 + pi_1_1 >= 0
500p_t_3_o1 + 200p_t_3_o2 + 0p_t_3_o3 - pi_3_1 - 500p_t_2_o1 -
200p_t_2_o2 - 0p_
t_2_o3 + pi_2_1 >= 0
bounds
p_t_1_o1 >= 0
p_t_1_o2 >= 0
p_t_1_o3 >= 0
-inf <= pi_1_1 <= +inf
p_t_2_o1 >= 0
p_t_2_o2 >= 0
p_t_2_o3 >= 0
-inf <= pi_2_1 <= +inf
p_t_3_o1 >= 0
p_t_3_o2 >= 0
p_t_3_o3 >= 0
-inf <= pi_3_1 <= +inf
end
```

(We did not cover slides after this one in class; the below is just in case you're interested.)

# Summary of approach

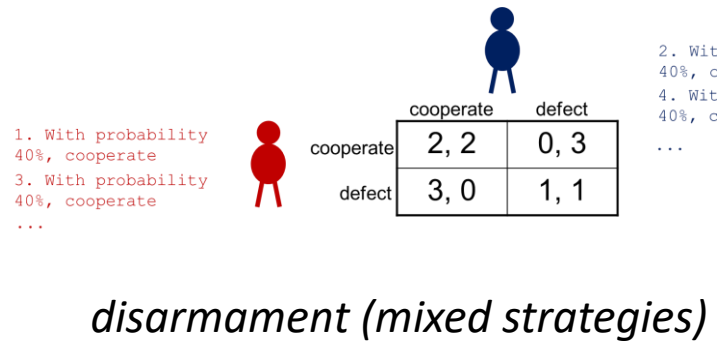
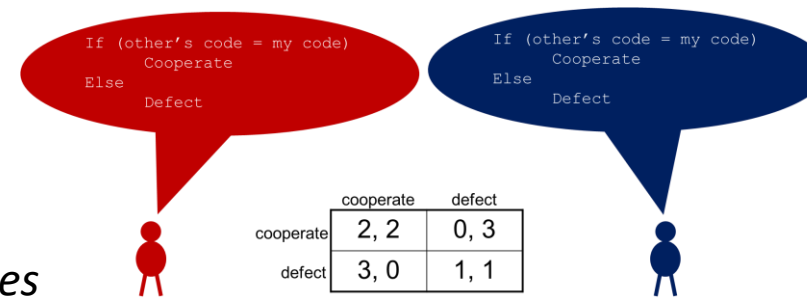
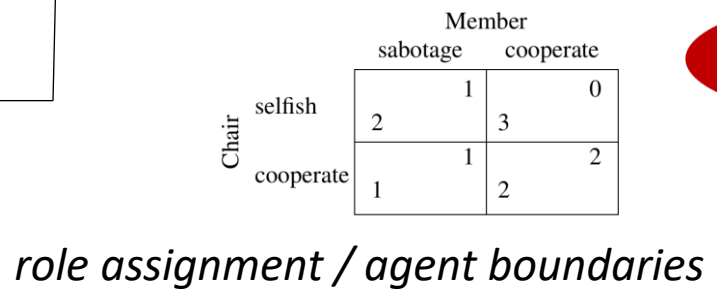
- Game-theoretic failures to cooperate can happen **even with almost perfectly aligned agents**
- Some ways of getting to cooperation make sense for **humans** as well...
- ... but there are others that seem more natural for **(advanced) AI agents**
- Let's not unnecessarily limit our toolkit!

	100	90	80	70	60	50	40	30	20	10	0
100	111, 111	90, 112	80, 102	70, 92	60, 82	50, 72	40, 62	30, 52	20, 42	10, 32	0, 22
90	112, 90	101, 101	80, 102	70, 92	60, 82	50, 72	40, 62	30, 52	20, 42	10, 32	0, 22
80	102, 80	102, 80	91, 91	70, 92	60, 82	50, 72	40, 62	30, 52	20, 42	10, 32	0, 22
70	92, 70	92, 70	92, 70	81, 81	60, 82	50, 72	40, 62	30, 52	20, 42	10, 32	0, 22
60	82, 60	82, 60	82, 60	82, 60	71, 71	50, 72	40, 62	30, 52	20, 42	10, 32	0, 22
50	72, 50	72, 50	72, 50	72, 50	72, 50	61, 61	40, 62	30, 52	20, 42	10, 32	0, 22
40	62, 40	62, 40	62, 40	62, 40	62, 40	62, 40	51, 51	30, 52	20, 42	10, 32	0, 22
30	52, 30	52, 30	52, 30	52, 30	52, 30	52, 30	52, 30	41, 41	20, 42	10, 32	0, 22
20	42, 20	42, 20	42, 20	42, 20	42, 20	42, 20	42, 20	42, 20	31, 31	10, 32	0, 22
10	32, 10	32, 10	32, 10	32, 10	32, 10	32, 10	32, 10	32, 10	32, 10	21, 21	0, 22
0	22, 0	22, 0	22, 0	22, 0	22, 0	22, 0	22, 0	22, 0	22, 0	22, 0	11, 11

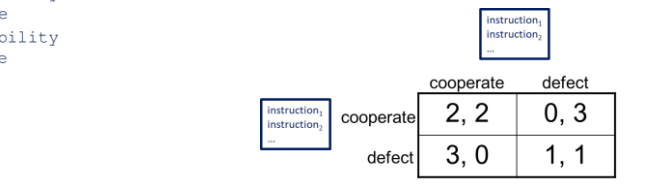


	GR	ST
PF	4,1	-0.5, -0.5
PD	-6, 8	-0.5, -0.5

*disarmament (pure strategies)*



2. With probability 40%, cooperate  
4. With probability 40%, cooperate  
...



# Many open questions

- What are the **foundations of game theory for highly advanced AI**?
- How should an agent play with other agents **with overlapping code**?  
With **visible code**?
- How should an agent play when it may be being **simulated**? When it **can't remember the past**?
- What **design decisions** can improve cooperation?
  - How **realistic** are they? How do we make them more so?
  - How **robust** are they? How do we make them more so?
- What is the role of **learning**?
  - Can we design learning algorithms that converge to **good** equilibria?
  - In contexts of **logical uncertainty**?
- ...



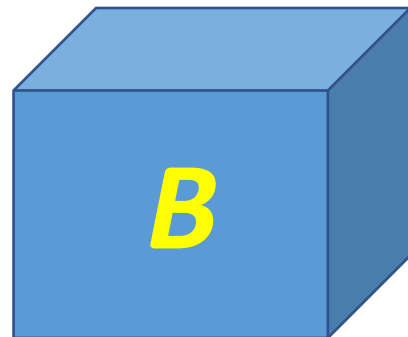
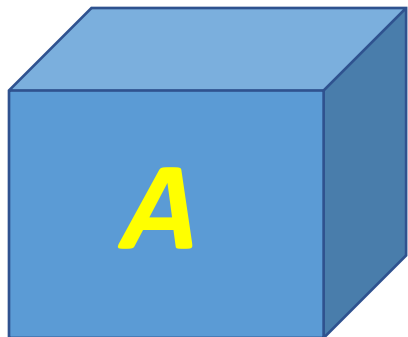
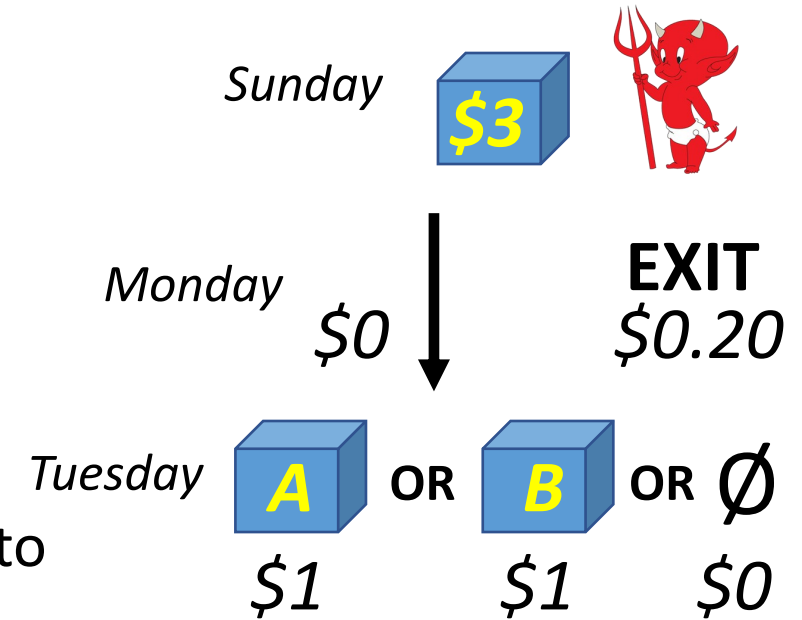
# Turning causal decision theorists into money pumps

[[Oesterheld and C., Phil. Quarterly](#)]



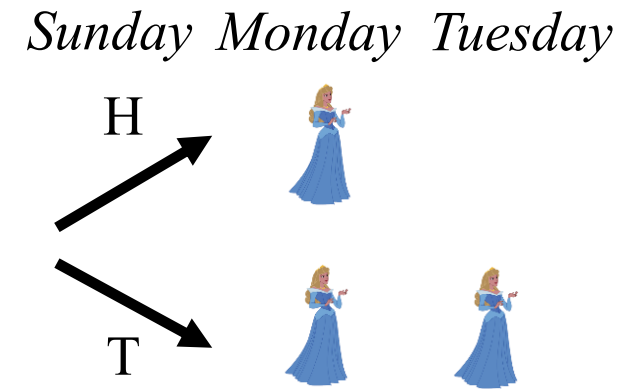
- **Adversarial Offer:**

- Demon (really, any good predictor) put \$3 into each box it predicted you would not choose
- Each box costs \$1 to open; can open at most one
- Demon 75% accurate (you have no access to randomization)
- CDT will choose one box, *knowing that it will regret doing so*
- Can add earlier **opt-out** step where the demon promises not to make the adversarial offer later, if you pay the demon \$0.20 now



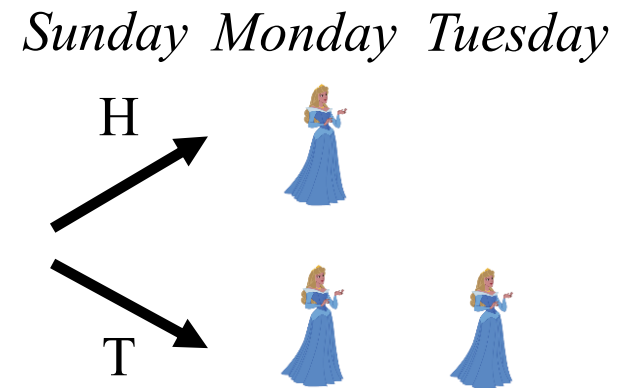
# Taking advantage of a Halfer [\[Hitchcock'04\]](#)

- Offer Beauty the following bet *whenever she awakens*:
  - If the coin landed Heads, Beauty receives 11
  - If it landed Tails, Beauty pays 10
- Argument: Halfer will accept, Thirder won't
- If it's Heads, Halfer Beauty will get +11
- If it's Tails, Halfer Beauty will get **-20**
- Can combine with another bet to make Halfer Beauty end up with a sure loss (a Dutch book)



# Evidential decision theory

- Idea: when considering how to make a decision, should consider **what it would tell you about the world if you made that decision**
- EDT Halfer: “With prob.  $\frac{1}{2}$ , it’s Heads; if I accept, I will end up with 11. With prob.  $\frac{1}{2}$ , it’s Tails; if I accept, then *I expect to accept the other day as well and end up with -20*. I shouldn’t accept.”
- As opposed to more traditional **causal decision theory (CDT)**
- CDT Halfer: “With prob.  $\frac{1}{2}$ , it’s Heads; if I accept, it will pay off 11. With prob.  $\frac{1}{2}$ , it’s Tails; if I accept, it will pay off -10. *Whatever I do on the other day I can’t affect right now*. I should accept.”
- EDT Thirder can also be Dutch booked
- CDT Thirder and EDT Halfer cannot
  - [Draper & Pust ‘08; Briggs ‘10]
- EDTers arguably can in more general setting
  - [C., Synthese’15]
  - ... though we’ve argued against CDT in other work [Oosterheld & C, Phil. Quarterly’21]



# Dutch book against EDT [C. 2015]

- Modified version of Sleeping Beauty where she wakes up in rooms of various colors

	WG (1/4)	WO (1/4)	BO (1/4)	BG (1/4)
Monday	white	white	black	black
Tuesday	grey	black	white	grey

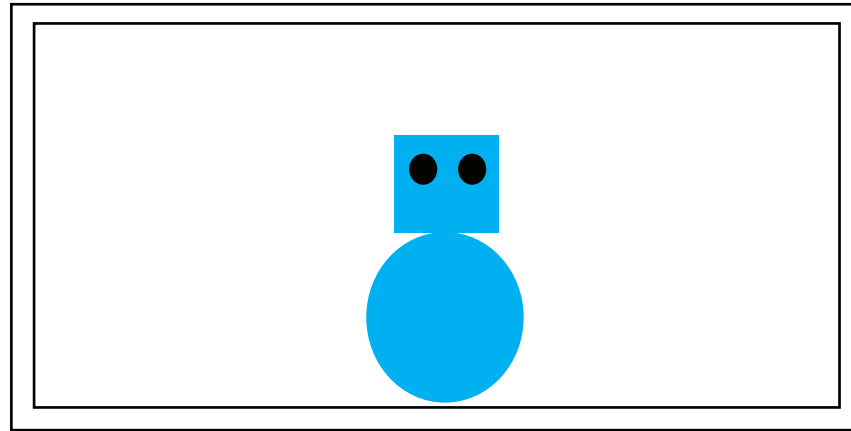
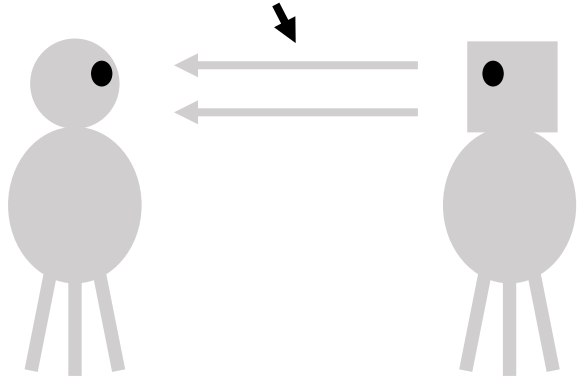
**Fig. 3** Sequences of coin tosses and corresponding room colors, as well as their probabilities, in the WBG Sleeping Beauty variant.

	WG (1/4)	WO (1/4)	BO (1/4)	BG (1/4)
Sunday	bet 1: 22	bet 1: -20	bet 1: -20	bet 1: 22
Monday	bet 2: -24	bet 2: 9	bet 2: 9	bet 2: -24
Tuesday	no bet	bet 2: 9	bet 2: 9	no bet
total gain from accepting all bets	-2	-2	-2	-2

**Fig. 4** The table shows which bet is offered when, as well as the net gain from accepting the bet in the corresponding possible world, for the Dutch book presented in this paper.

# Philosophy of “being present” somewhere, sometime

*simulated light (no direct correspondence to light in our world)*



1: world with creatures simulated on a computer

2: displayed perspective of one of the creatures

[Erkenntnis](#)

June 2019, Volume 84, [Issue 3](#), pp 727–739 | [Cite as](#)

## A Puzzle about Further Facts

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Vincent Conitzer 

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## Abstract

In metaphysics, there are a number of distinct but related questions about the existence of “further facts”—facts that are contingent relative to the physical structure of the universe. These include further facts about qualia, personal identity, and time. In this article I provide a sequence of examples involving computer simulations, ranging from one in which the protagonist can clearly conclude such further facts exist to one that describes our own condition. This raises the question of where along the sequence (if at all) the protagonist stops being able to soundly conclude that further facts exist.

## Keywords

Metaphysics

Philosophy of mind

Epistemology

See also: [\[Hare 2007-2010, Valberg 2007, Hellie 2013, Merlo 2016, ...\]](#)

- To get from 1 to 2, need *additional* code to:
  - A. determine *in which real-world colors* to display perception
  - B. *which agent’s* perspective to display
- Is 2 more like our own conscious experience than 1? If so, are there *further facts* about presence, perhaps beyond physics as we currently understand it?

# Absentminded Driver Problem

[Piccione and Rubinstein, 1997]

- Driver on monotonous highway wants to take second exit, but exits are indistinguishable and driver is forgetful
- Deterministic (behavioral) strategies are not *stable*
- Optimal **randomized strategy**: exit with probability  $p$  where  $p$  maximizes  $4p(1-p) + (1-p)^2 = -3p^2 + 2p + 1$ , so  $p^* = 1/3$
- What about “from the inside”? P&R analysis: Let  $b$  be the belief/credence that we’re at  $X$ , and  $p$  the probability that we exit. Maximize with respect to  $p$ :  $(1-b)(4p+1(1-p)) + b(4p(1-p) + 1(1-p)^2) = -3bp^2 + (3-b)p + 1$ , so  $p^* = (3-b) / (6b) = 1/(2b) - 1/6$
- But if  $p = 1/3$ , then  $b = 3/5$ , which would give  $p^* = 5/6 - 1/6 = 2/3$ ? So also not stable?
- Resembles EDT reasoning... But not really halving... Shouldn’t  $b$  depend on  $p$ ...

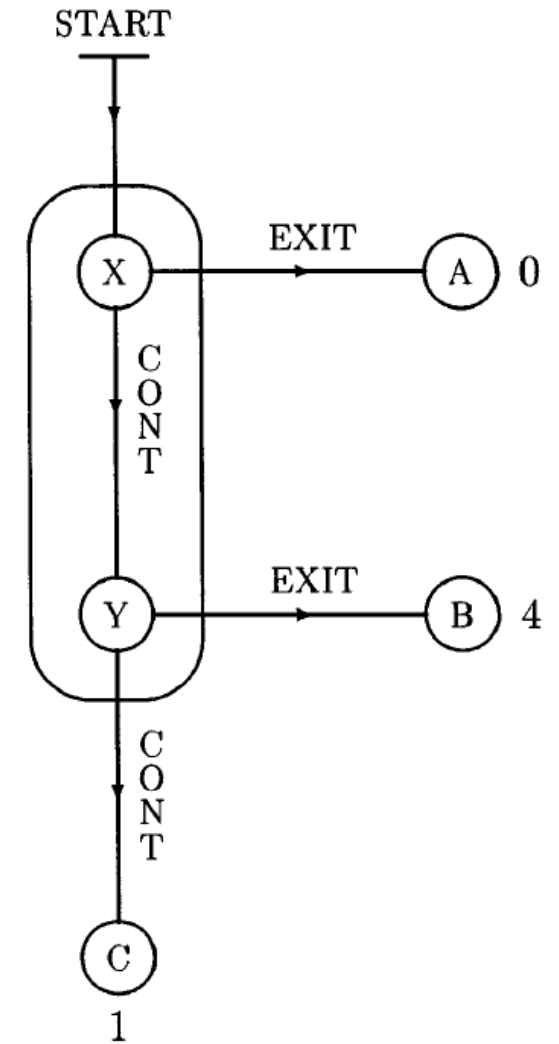


FIG. 1. The absent-minded driver problem.

Image from Aumann, Hart, Perry 1997

# A different analysis

[Aumann, Hart, Perry, 1997]

- AHP reason more along thirder / CDT lines:
- Imagine we normally expect to play  $p = 1/3$ . Should we deviate **this time only**?
- If we exit now, get  $(3/5)*0 + (2/5)*4 = 8/5$
- If we continue now, get  $(3/5)*((1/3)*4+(2/3)*1) + (2/5)*1 = 8/5$
- So indifferent and willing to randomize (equilibrium)

## • Questions

• *Joint work with:*



Scott Emmons



Caspar Oesterheld



Andrew Critch



Stuart Russell

- Does this always work? Yes! (See also [Taylor \[2016\]](#))
- Does some version of EDT work with some version of belief formation?

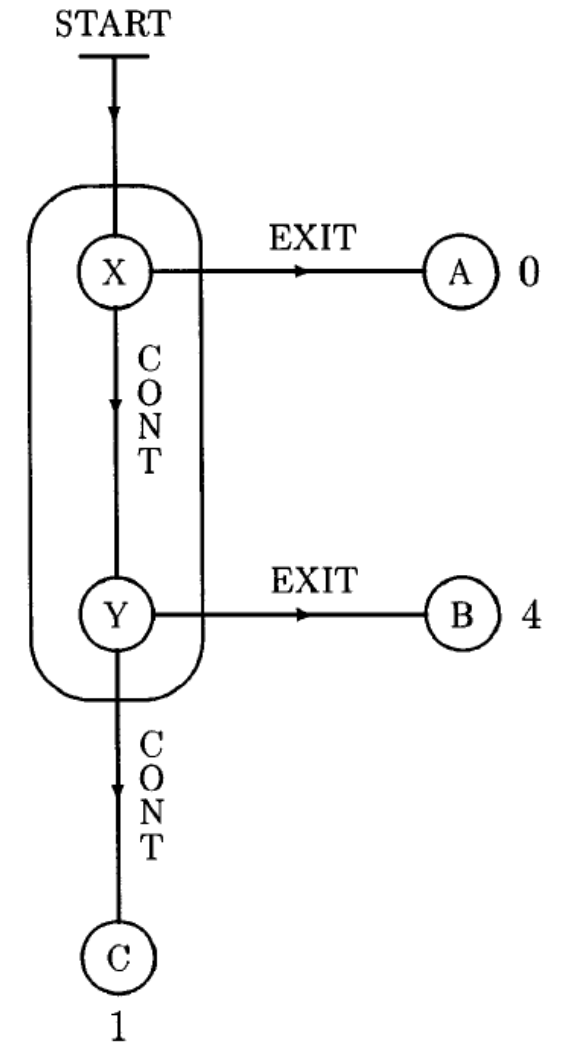
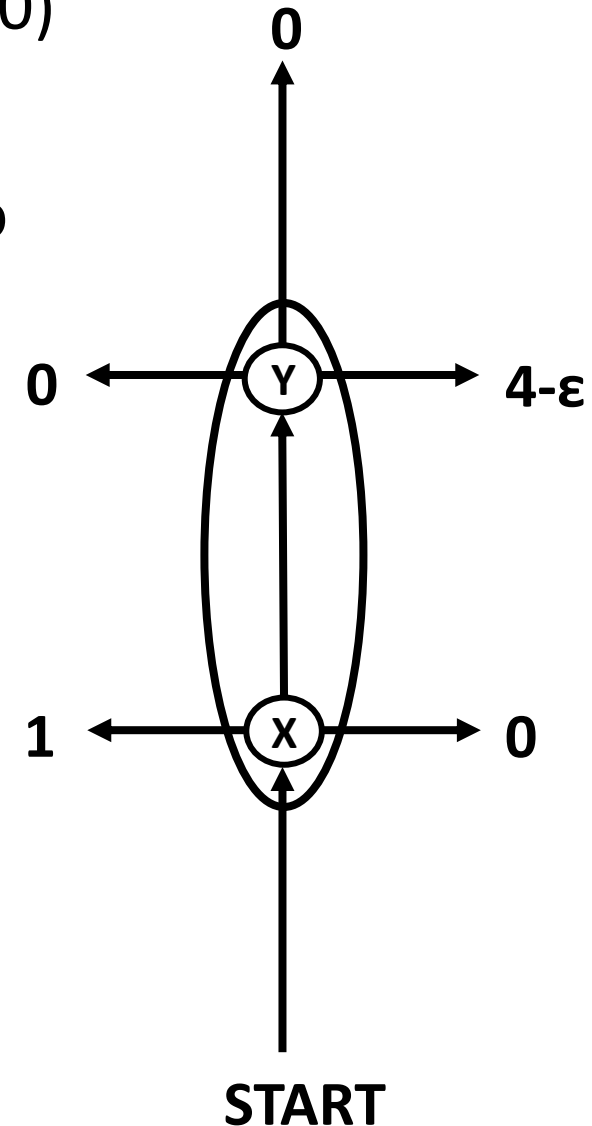


FIG. 1. The absent-minded driver problem.

Image from Aumann, Hart, Perry 1997

# A challenging example for the evidential decision theorist

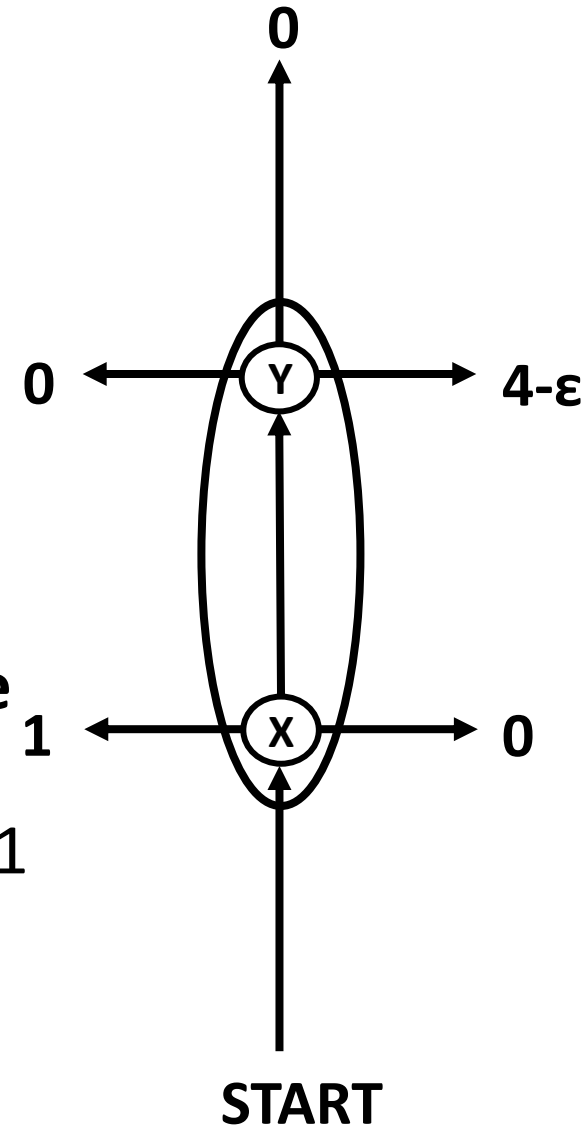
- Optimal strategy to commit to is to just go left:  $(p_l, p_s, p_r) = (1, 0, 0)$
- If you're at an intersection, what does EDT say you should do?
- When considering  $(p_l, p_s, p_r) = (1, 0, 0)$ , you presumably expect to be at X and get 1 (really just need: no more than 1)
- When considering  $(p_l, p_s, p_r) = (0, \frac{1}{2}, \frac{1}{2})$ , then say  $b$  is your subjective probability of being at Y
  - **Assume:**  $b > 0$
  - **Assume:**  $b$  is not a function of  $\varepsilon$
- So, expected utility:  $b * \frac{1}{2} * (4 - \varepsilon) + (1 - b) * \frac{1}{4} * (4 - \varepsilon) = 1 + b - \frac{1}{4}\varepsilon - \frac{1}{4}b\varepsilon$
- For sufficiently small  $\varepsilon$  this is greater than 1
- Hence EDT suggests  $(0, \frac{1}{2}, \frac{1}{2})$  over  $(1, 0, 0)$ !
- ... right? ... right?





# A way for EDT to get the right answer (+SSA)

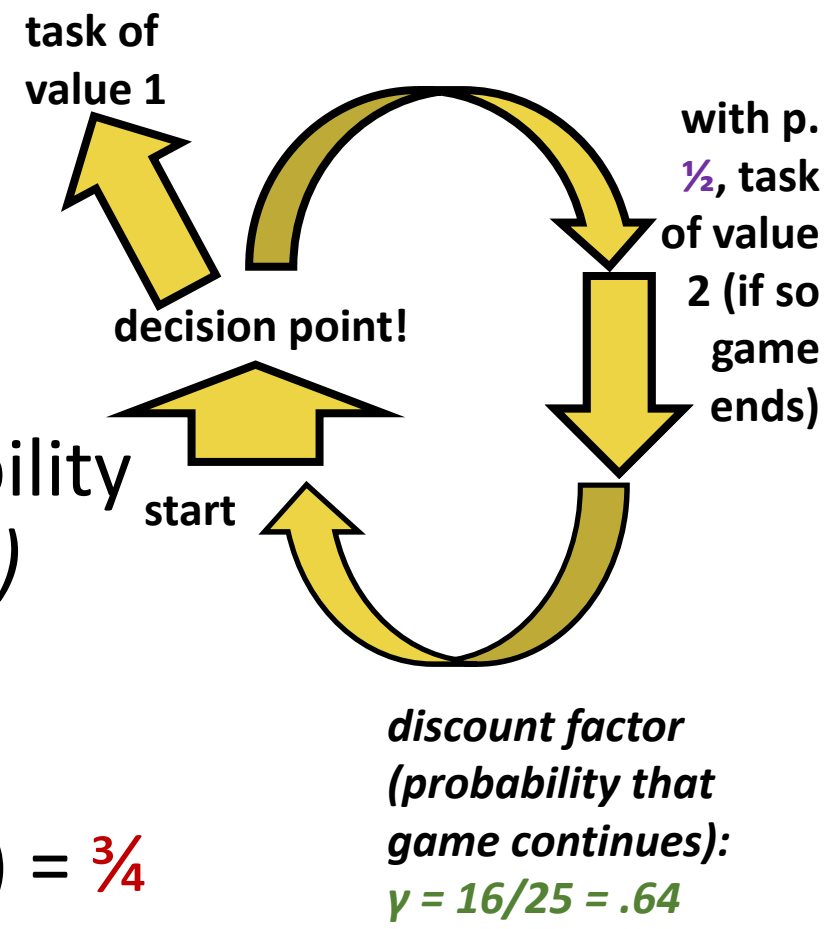
- Consider probabilities of **whole trajectories, plus where you are**, under strategy  $(0, \frac{1}{2}, \frac{1}{2})$ , in a **halving sort of way**
- $P(XY(4-\epsilon), @X) = P(XY(4-\epsilon)) * P(@X | XY(4-\epsilon)) = \frac{1}{4} * \frac{1}{2}$
- $P(XY(4-\epsilon), @Y) = P(XY(4-\epsilon)) * P(@Y | XY(4-\epsilon)) = \frac{1}{4} * \frac{1}{2}$
- Any other trajectory with positive probability gives payoff 0
- So expected utility is  $2 * \frac{1}{4} * \frac{1}{2} * (4-\epsilon) = 1 - \epsilon/4$ , which is worse than 1, so EDT gets the right answer
- *What just happened?*
- Under this way of reasoning, if you tell me that I'm at X, it's **more likely** that I'm on trajectory X(0) than on one of the XY ones
- $P(XY(4-\epsilon), @X) = \frac{1}{4} * \frac{1}{2}$  ;  $P(XY(0), @X) = \frac{1}{4} * \frac{1}{2}$  ;  $P(X(0), @X) = \frac{1}{2} * 1$
- So  $P(X(0) | @X) = \frac{1}{2} / (\frac{1}{2} + \frac{1}{4}) = \frac{2}{3}$  (**not**  $\frac{1}{2}$ )
- Previous slide had **hidden assumption**: *where I am carries no information about my **future** coin tosses*



# Making decisions with imperfect recall

[cf. absentminded driver problem: PR97, AHP97]

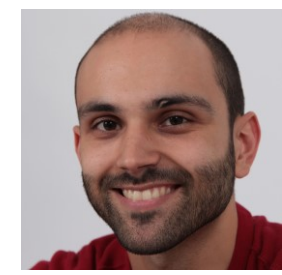
- Optimal strategy without recall: go Right with probability  $5/8$ . (*Outside view.*) Follow that.
- You arrive at decision point. What is the probability that you're there for the first time? (*Inside view.*)
- **Thirder:** in expectation 1 first awakening, and  $(1/2)(5/8)(16/25) / (1-(5/8)(16/25)) = 1/3$  later awakenings, so probability of first time =  $1/(4/3) = 3/4$
- Going Left gives 1 and going Right gives  $(1/2)(3/4)(2) + ((1/2)(3/4)+(1/4))(16/25)(3/8) / (1-(5/8)(16/25)) = 1$
- **Theorem.** This is always true!
- ... but can have other equilibria



Scott Emmons



Caspar Oesterheld



Andrew Critch



Stuart Russell

# Fraction of time replicator dynamic finds **best** solution

A	2	3	4	5	A	2	3	4	5
N					N				
2	0.93	0.81	0.68	0.65	2	0.58	0.45	0.40	0.33
3	0.81	0.70	0.58	0.46	3	0.57	0.35	0.29	0.27
4	0.76	0.58	0.36	0.34	4	0.53	0.37	0.28	0.25
5	0.69	0.43	0.36	0.30	5	0.51	0.33	0.33	0.24

(a) RandomGame

(b) CoordinationGame

*N = #players (or #nodes)*

*A = #actions per player (or per node)*

# Functional Decision Theory

[Soares and LeVine 2017; Yudkowsky and Soares 2017]

- One interpretation: *act as you would have precommitted to act*
- Avoids my EDT Dutch book (I think)
- ... still one-boxes in Newcomb's problem
- ... even one-boxes in Newcomb's problem **with transparent boxes**
- An odd example: Demon that will send you \$1,000 if it believes you would otherwise destroy everything (worth -\$1,000,000 to everyone)



Don't do it!

- FDT says you should destroy everything, *even if you only find out that you are playing this game after the entity has already decided not to give you the money* (too-late extortion?)