Non-Monetary Mechanism Design without Distributional Information: Using Scarce Audits Wisely

Yan Dai[1] Moïse Blanchard[2→3] Patrick Jaillet[1]

[1]MIT [2]Columbia [3]Georgia Tech

Challenge: Resource Allocation to Strategic Agents

1. **One central planner** maximize social welfare
2. K **strategic agents** self-interested (*i.e.*, may lie)
3. 1 **indivisible item**

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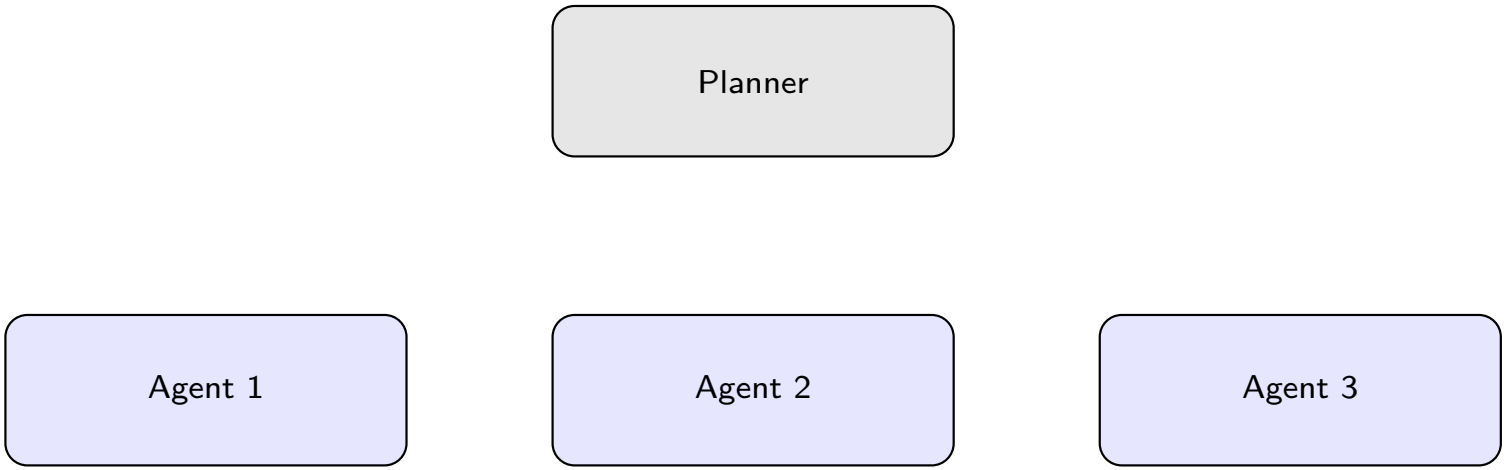

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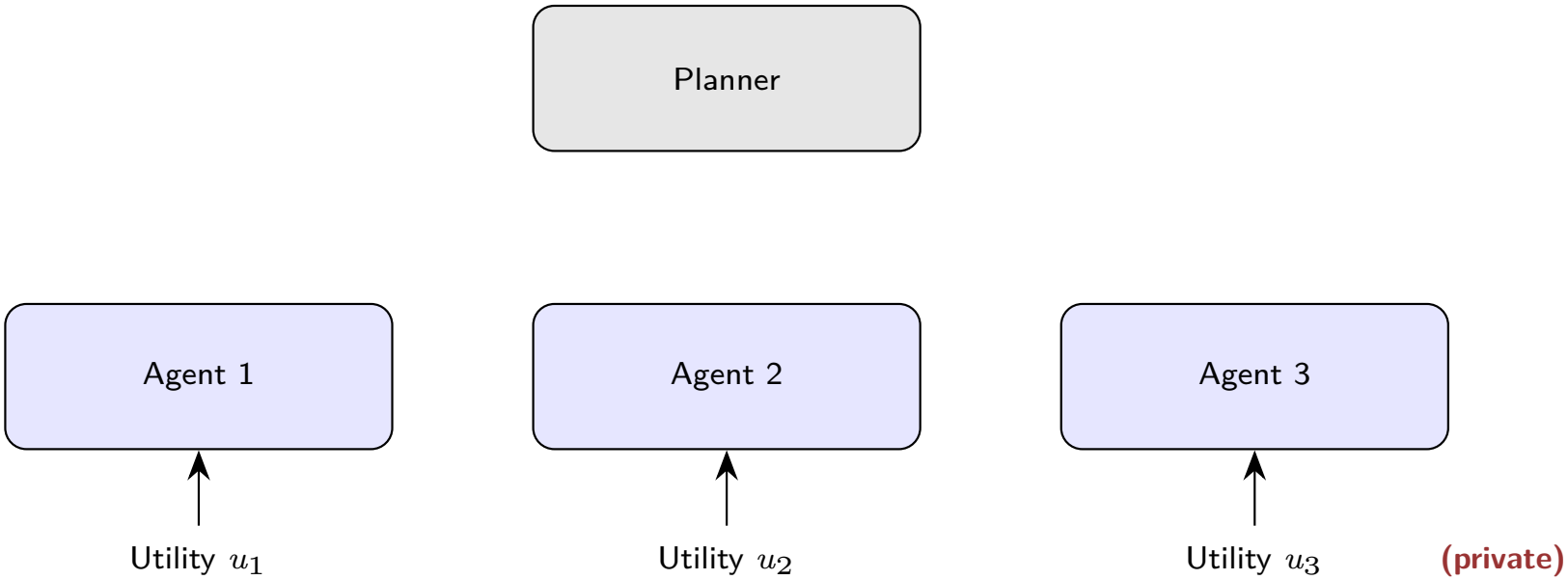

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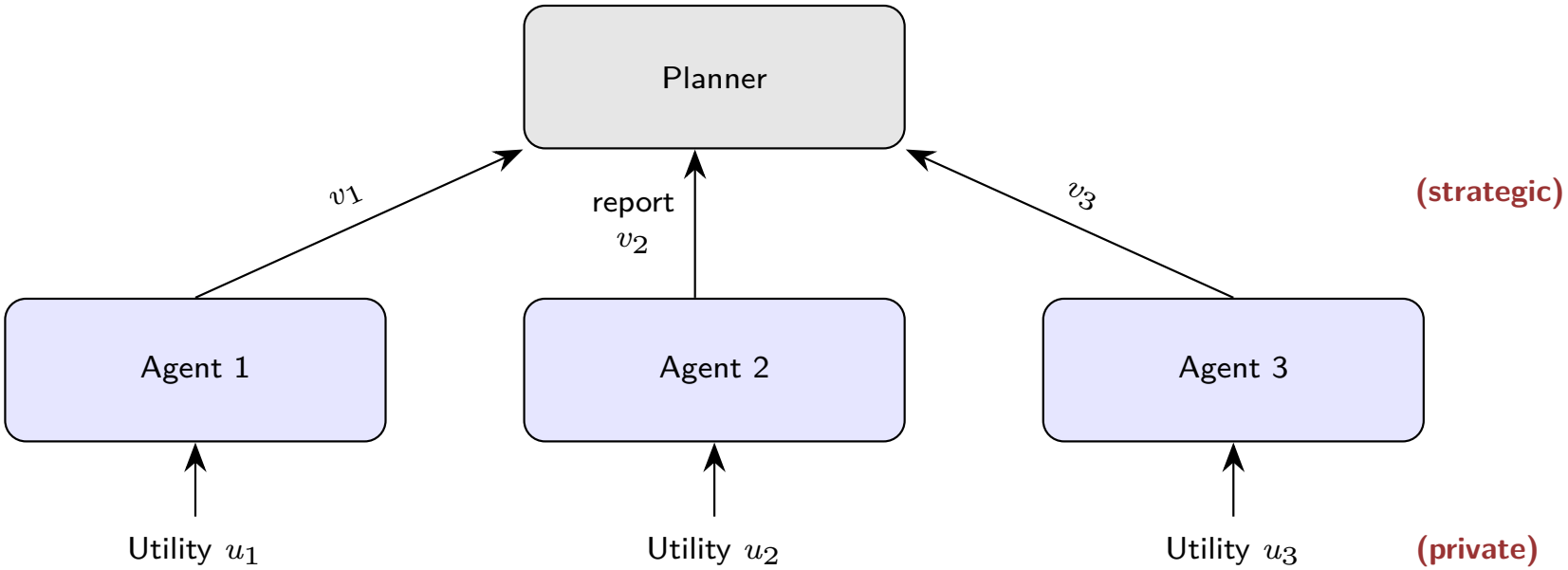

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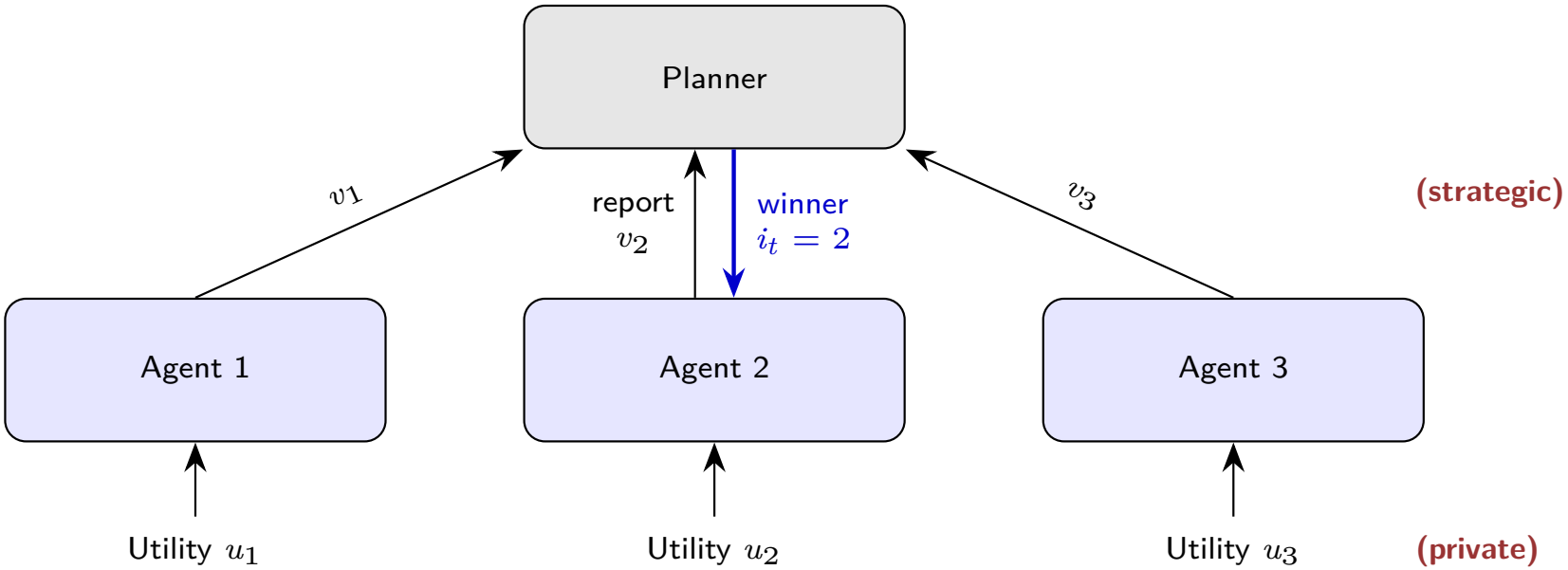

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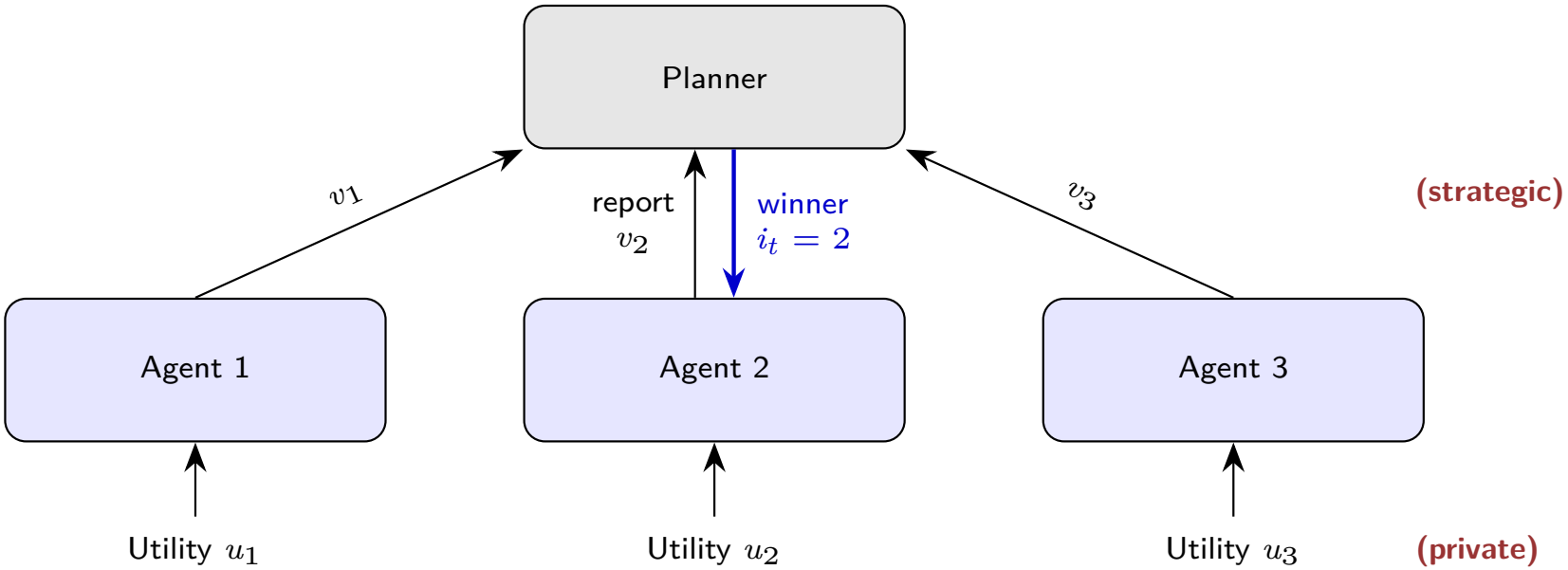

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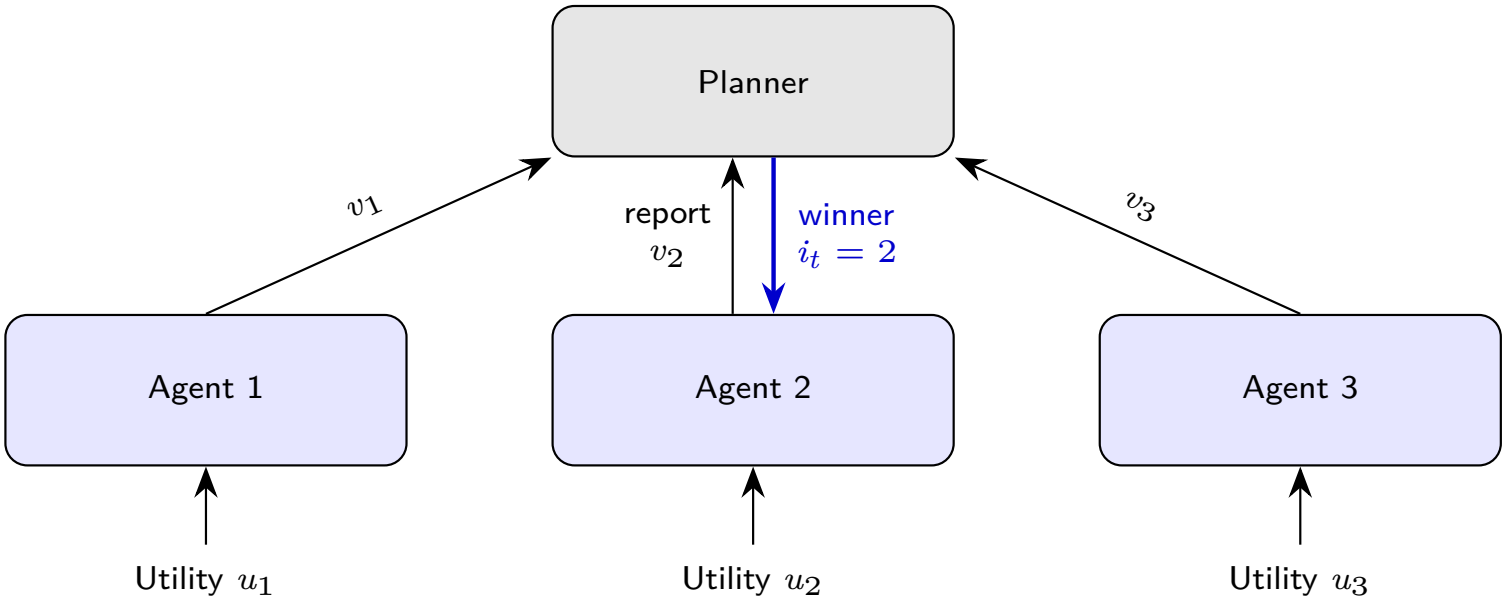
Two Objectives

Efficiency. max established utility u_{i_t} (unknown!)
Incentive-Compatibility. truthfully report $v_i \approx u_i$

Classical VCG Mechanisms



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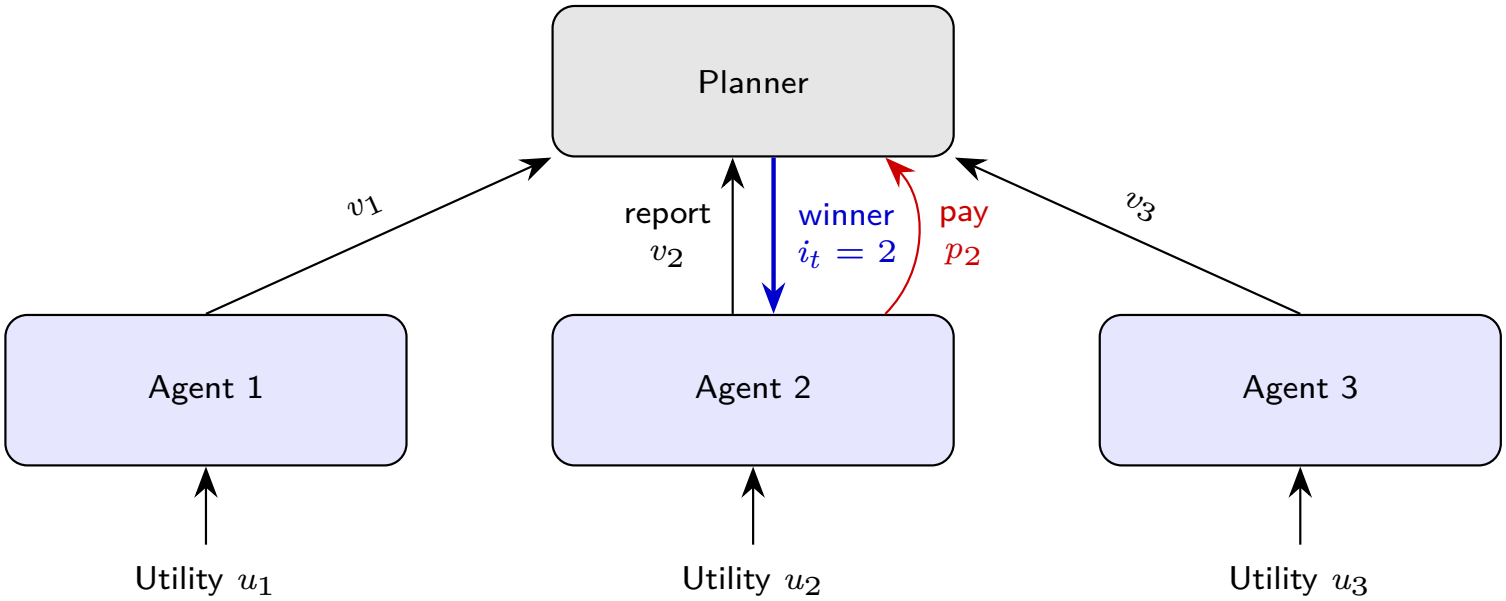

Monetary mechanisms: VCG family [Vic61; Cla71; Gro73]

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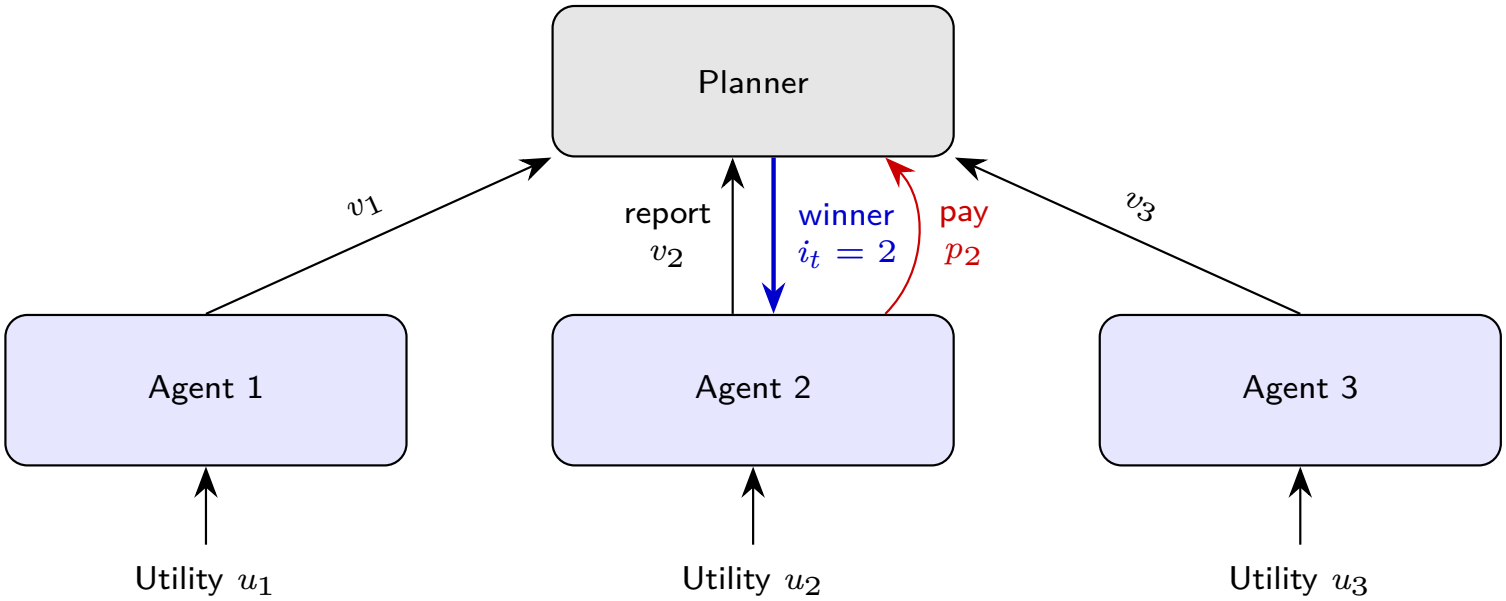

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3. GPU in company [ABDVVW22; PSMST22]

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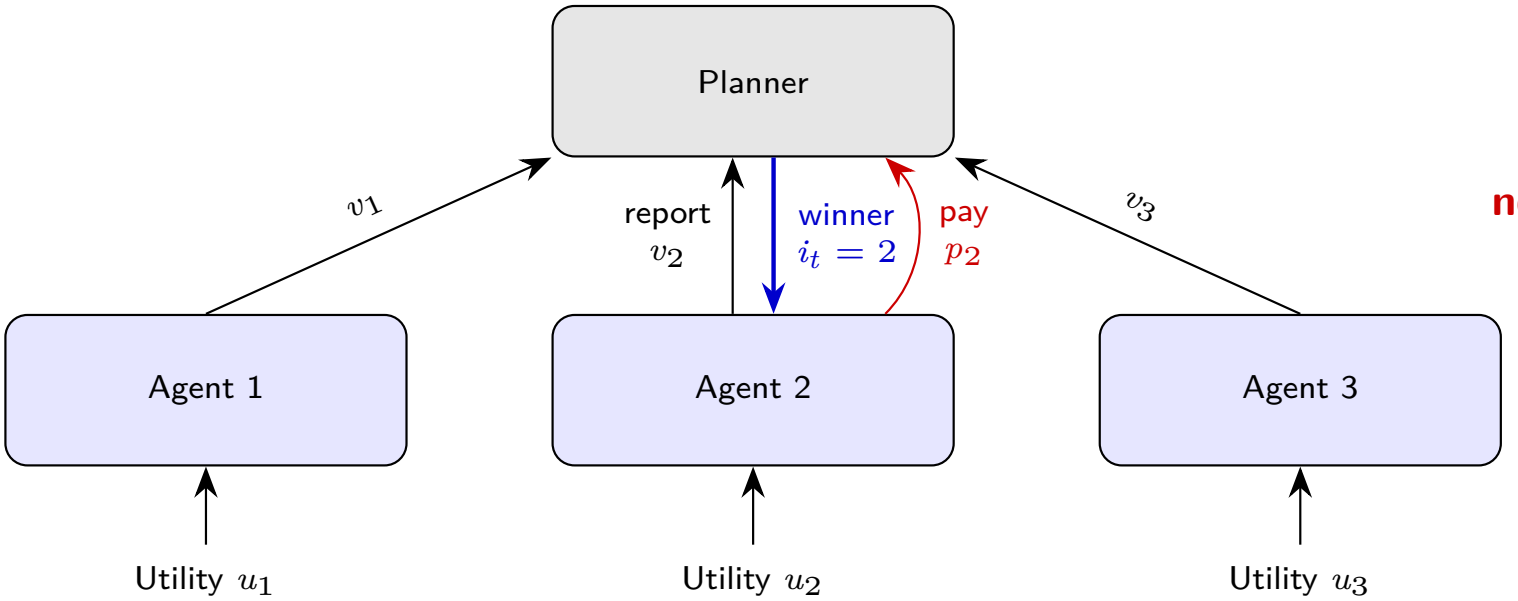

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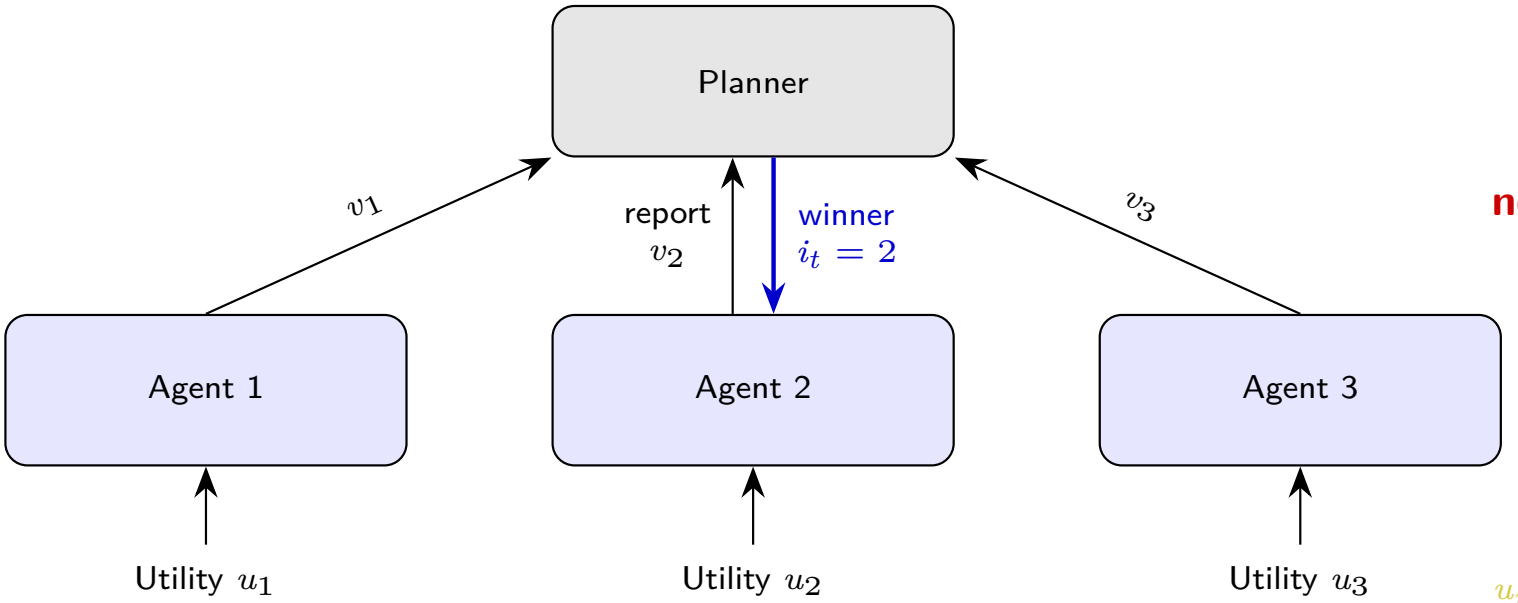

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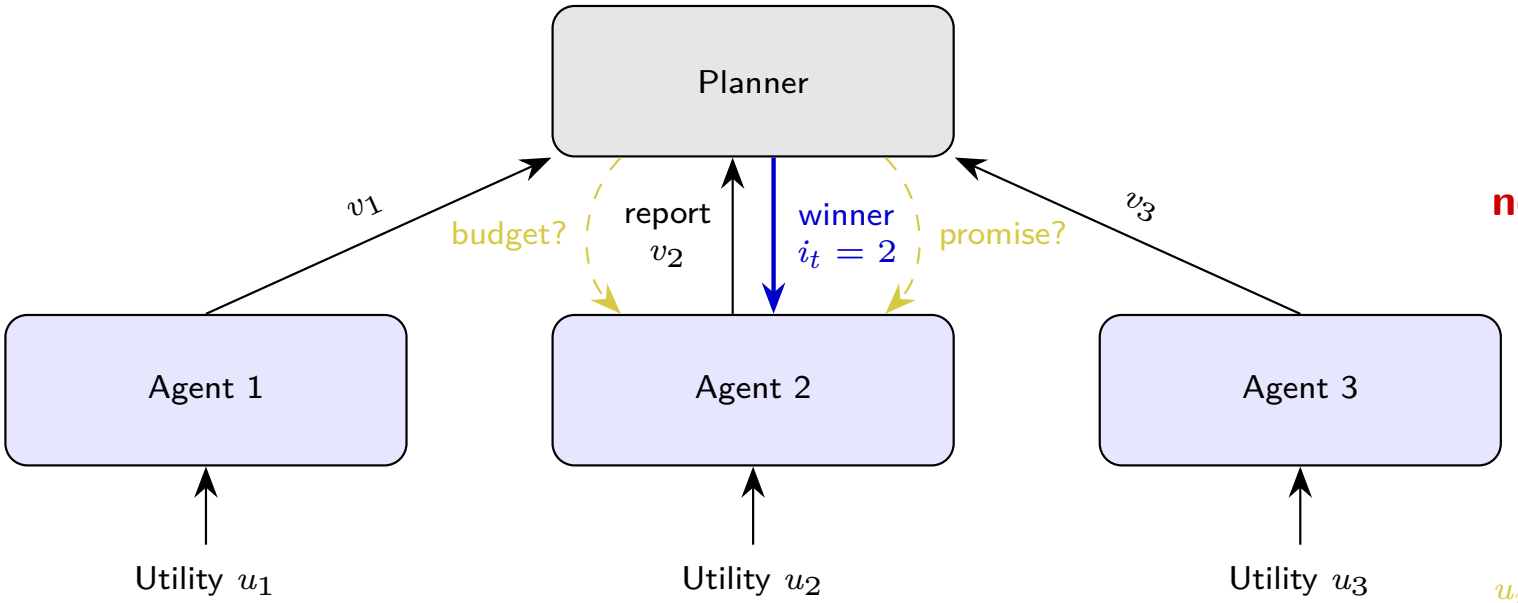

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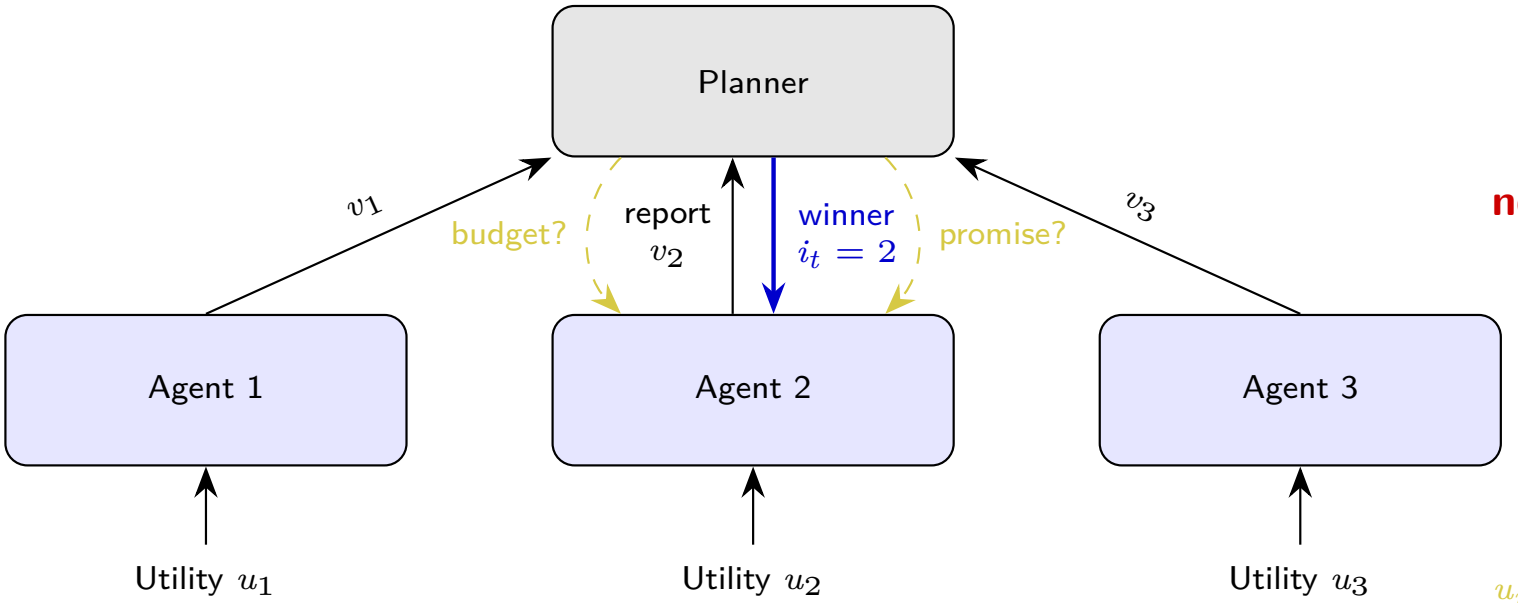

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1. Perfect knowledge on agents
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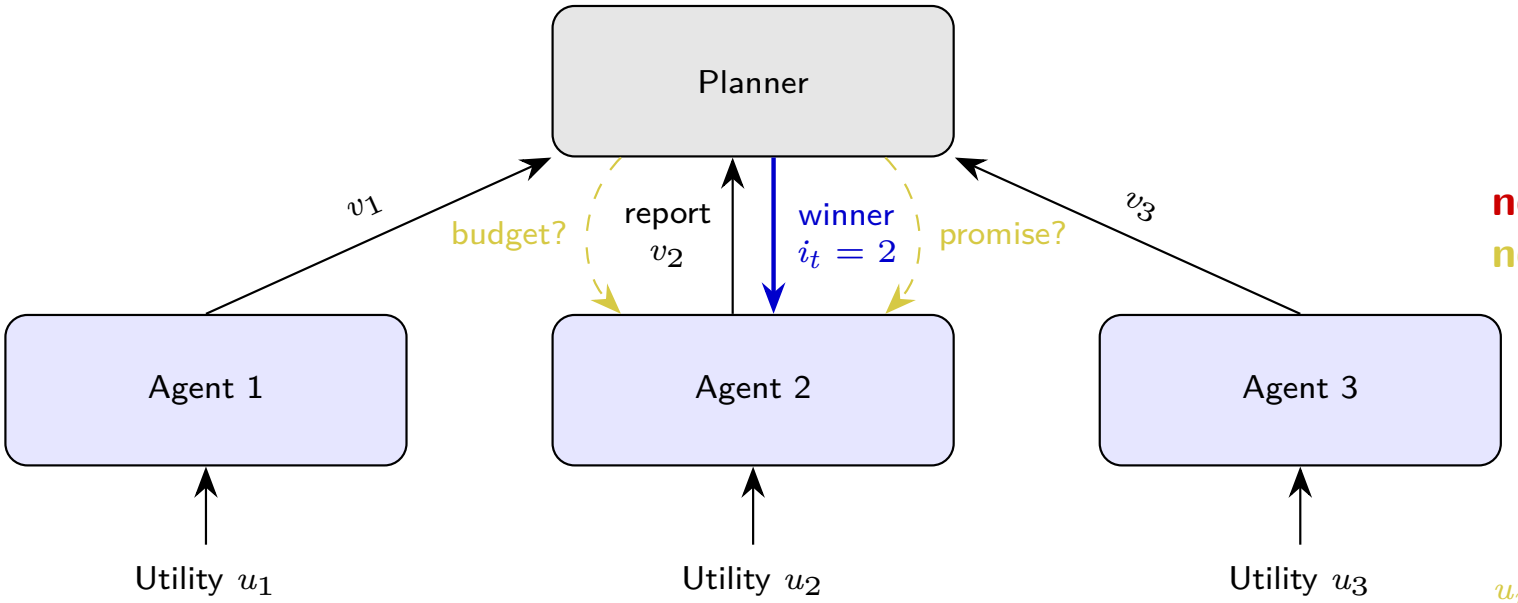

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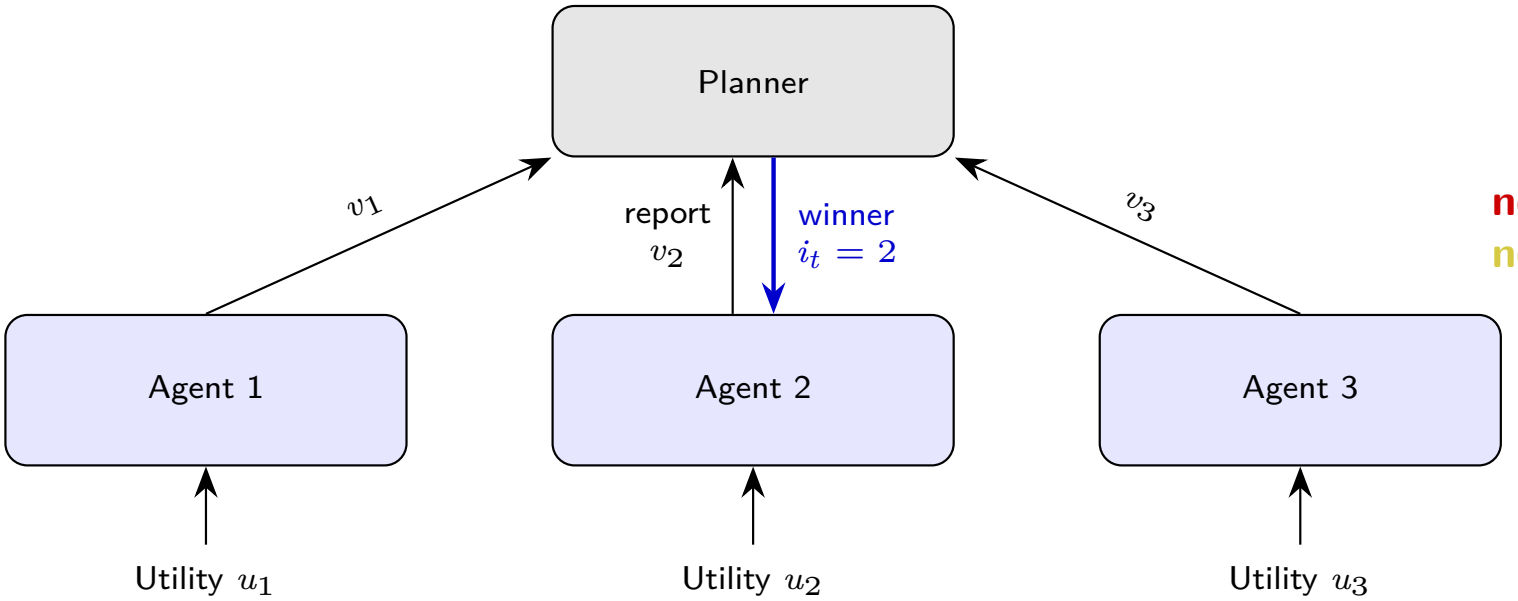

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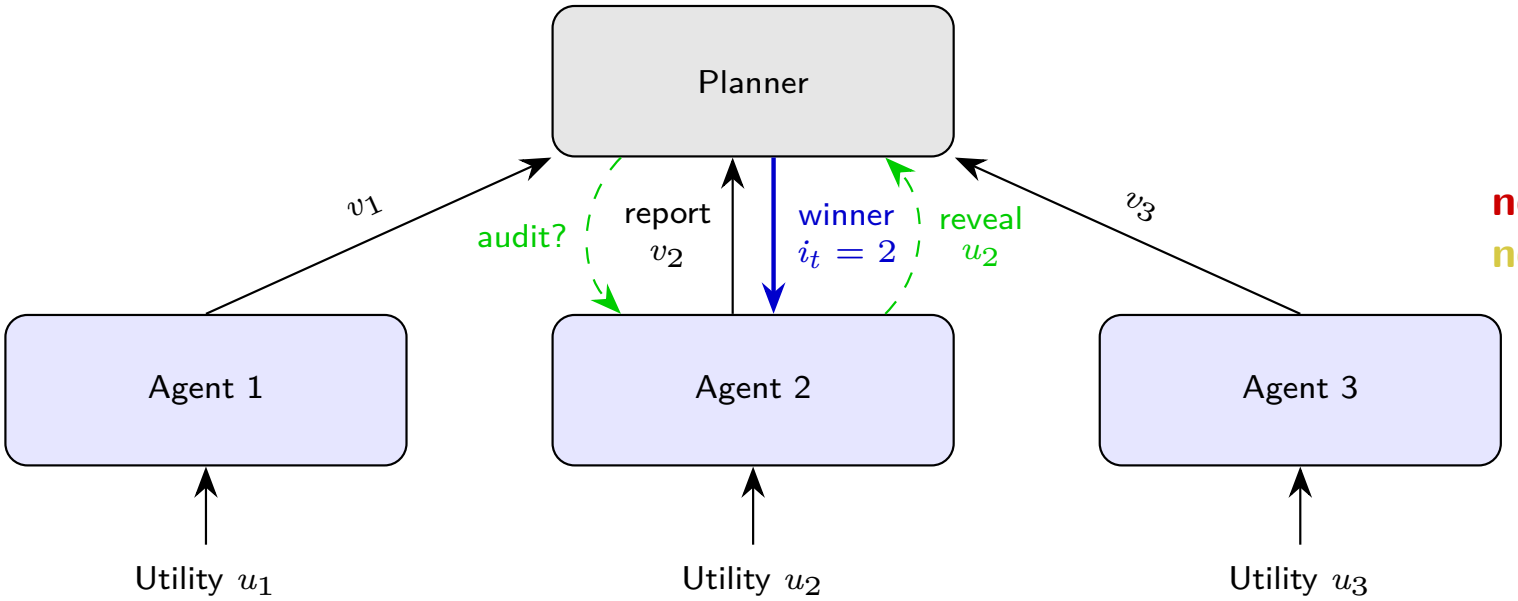

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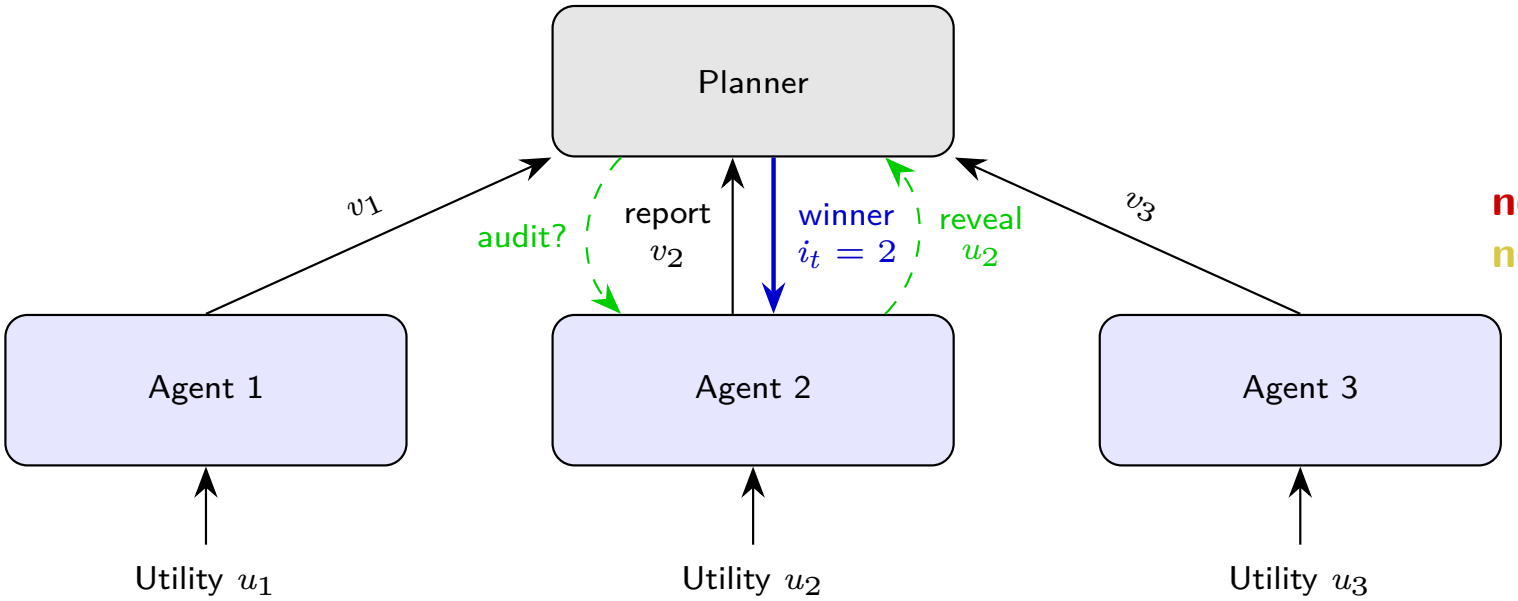

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Tradeoff between Regret & #Audits

Repeated allocation for T rounds:

1. **Social Welfare Regret.** $\mathcal{R}_T := \mathbb{E}[\sum_{t=1}^{T}(\max_i u_{t,i} - u_{t,i_t})]$

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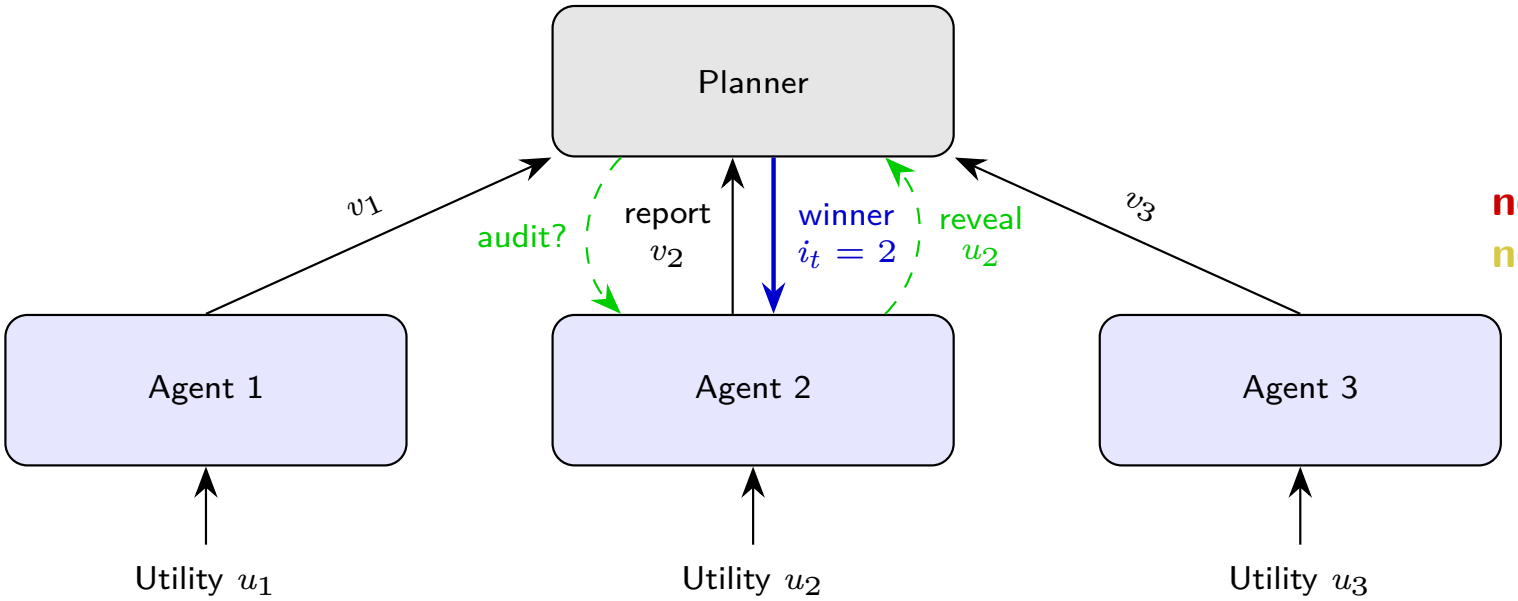

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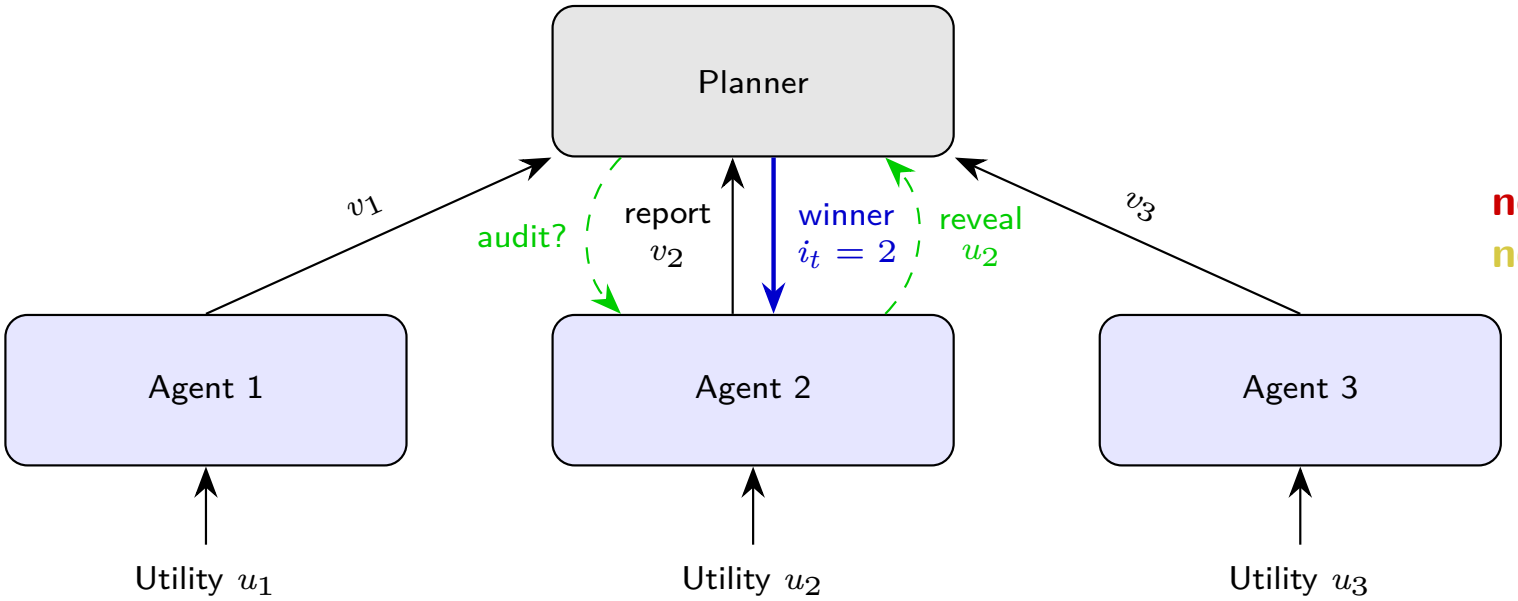

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   (Different from Online Learning regret!)
2. **Expected Number of Audits.** $\mathcal{B}_T := \mathbb{E}[\sum_{t=1}^{T} \mathbb{1}[\text{audit}]]$

Tradeoff between Regret & #Audits

$\exists$ Perfect Bayesian Equilibrium (PBE) π^*, *s.t.*

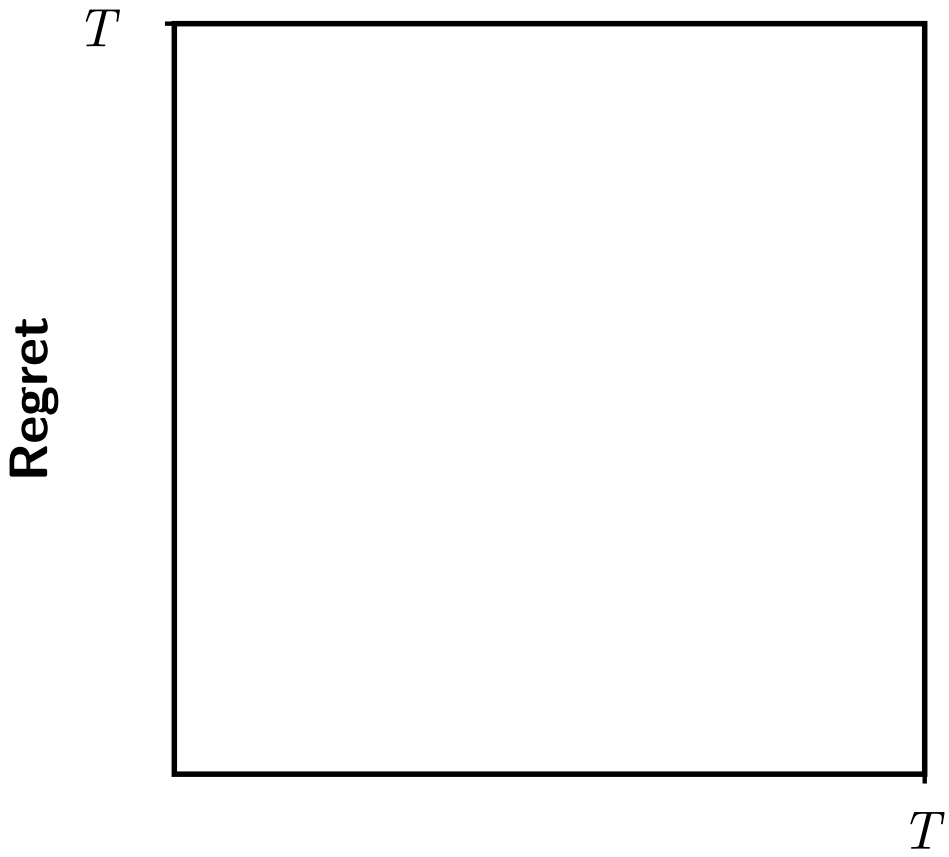

Figure: Regret vs $\mathbb{E}[\#\text{audits}]$

green possible; red impossible

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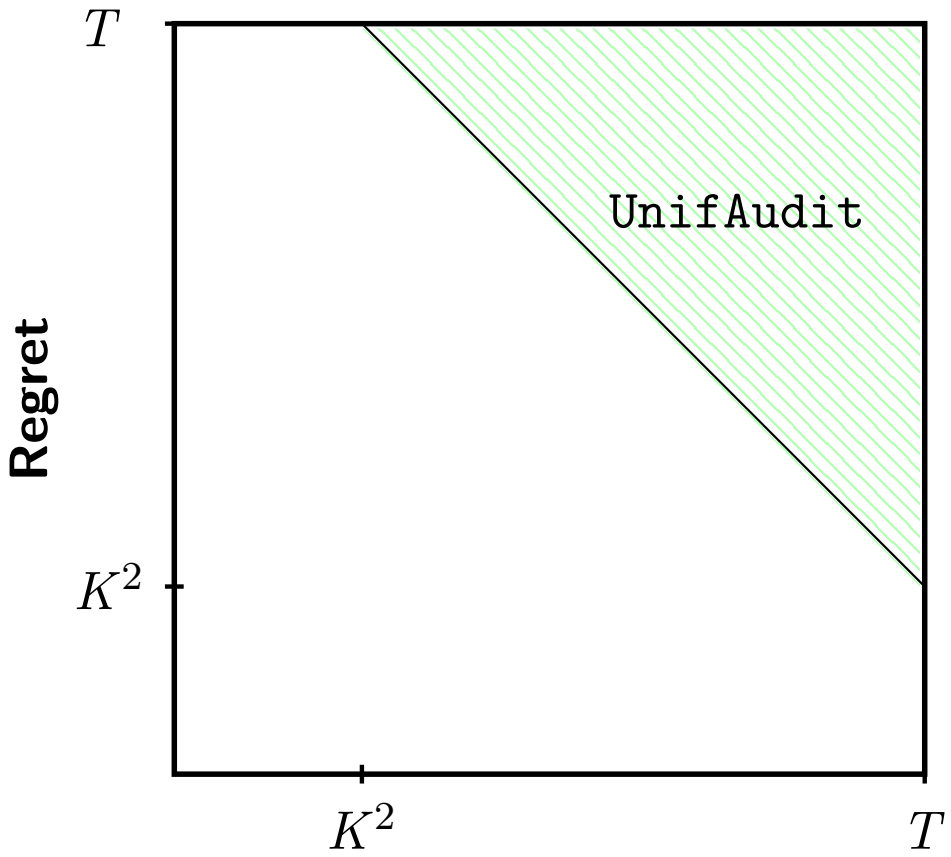

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Simple Mechanism:

`UnifAudit`.

$\mathcal{R}_T \leq \frac{K^2}{p}$ &

$\mathcal{B}_T \leq pT$.

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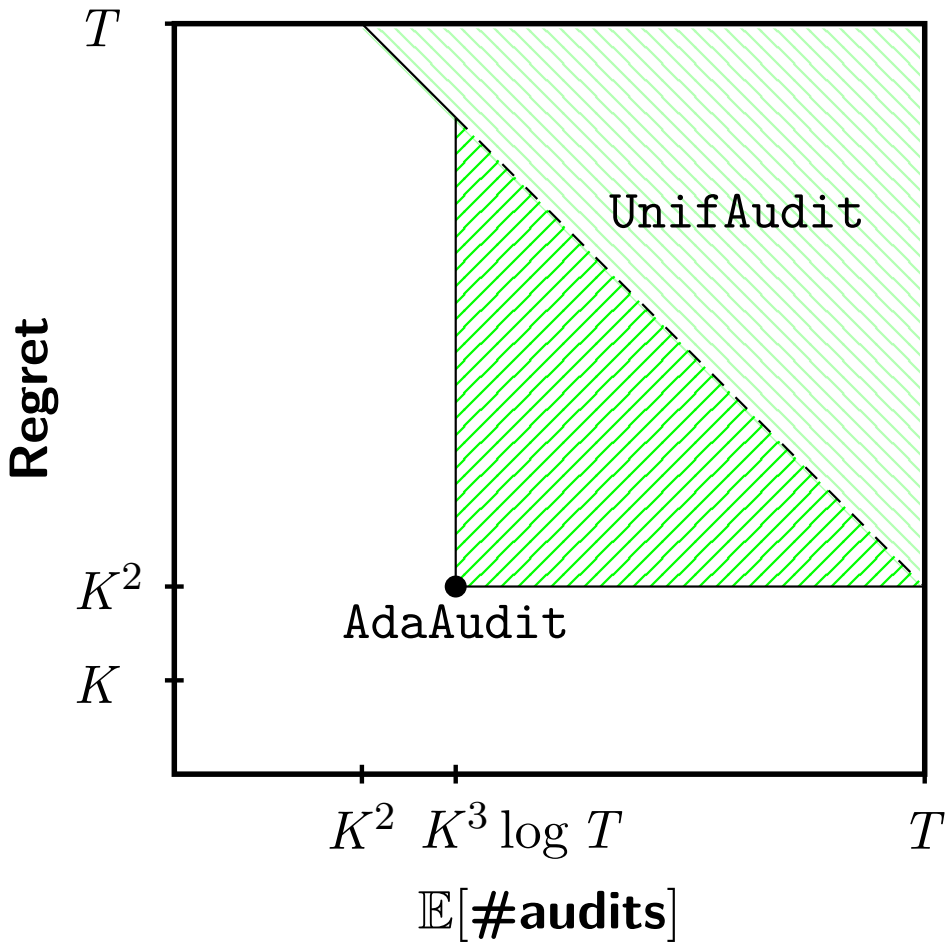

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Main Mechanism:

`AdaAudit`.

$\mathcal{R}_T \leq K^2$ &

$\mathcal{B}_T = \mathcal{O}(K^3 \log T)$.

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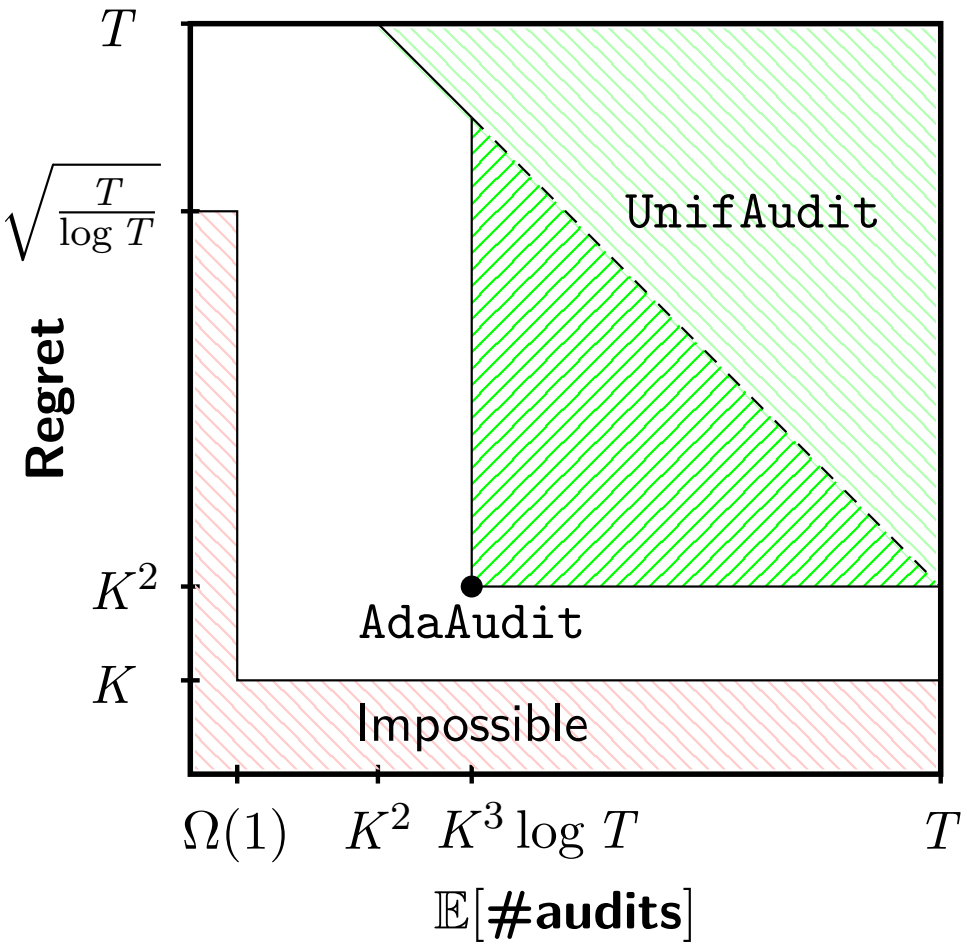

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Impossible.

$\mathcal{R}_T = \Omega(K)$;

$\mathcal{B}_T = \mathcal{O}(1) \Longrightarrow$

$\mathcal{R}_T = \Omega\left(\sqrt{\frac{T}{\log T}}\right)$.

One-Slide Technical Overview

1. **Future Punishment.** Audit reveals $v_{t,i} \neq u_{t,i} \Rightarrow$ never alloc again
2. **Adaptive Audits.**
3. **Learn via Flagging.**
4. **Auxiliary Games.**

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($V_i^{\text{alive}} := \mathbb{E}_{\text{all agents truthful}}[\sum_{\text{future round}} \text{gain of agent } i]$)

$\Longrightarrow$ (almost) always truthful & $\mathcal{B}_T = \widetilde{\mathcal{O}}(1)$

(truthful: get $\geq 0 + V_i^{\text{alive}}$; lie: get $\leq 1 + (1 - p_{t,i})\, V_i^{\text{alive}}$)

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   Need to estimate $\mathbb{E}_{\text{all agents truthful}}[\text{gain of agent } i]$ empirically but can't "condition on" concentration
   (since agents can strategize early; happy to explain offline)
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   ("victims" benefit from truthfully flagging $\Longrightarrow$ incentives aligned)

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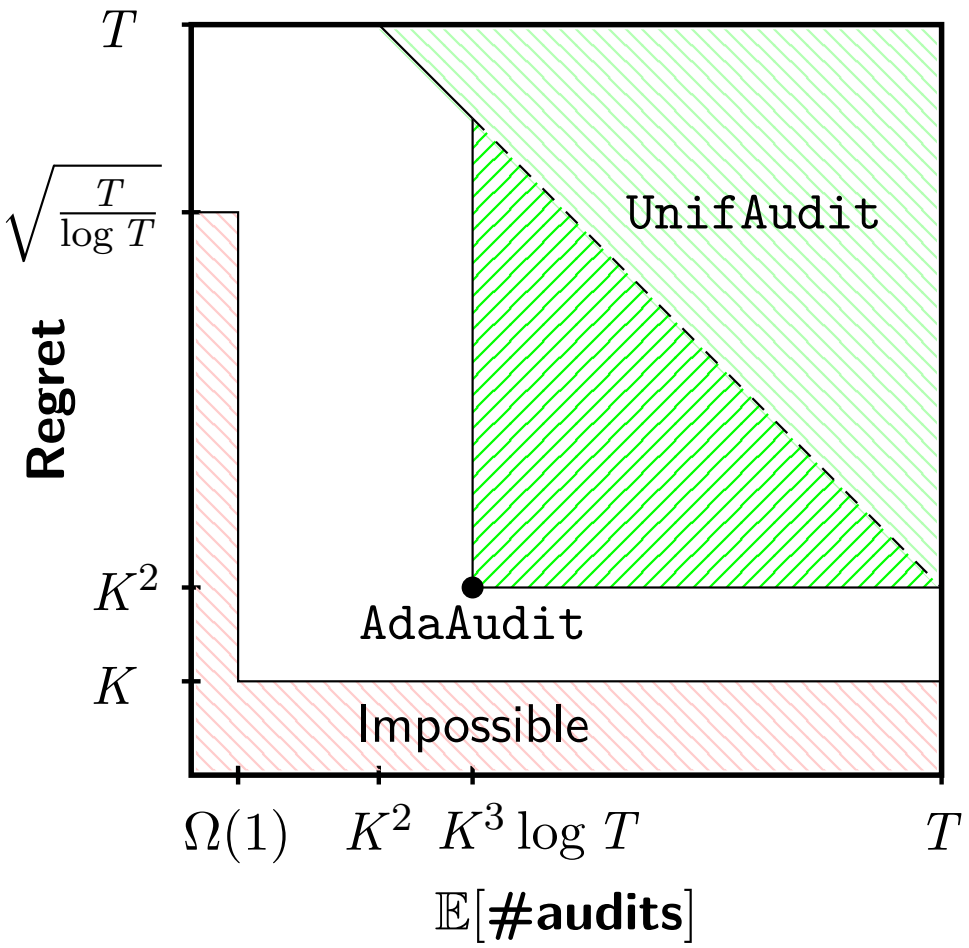
4. **Auxiliary Games.**
   Can't use revelation principle due to unknown / non-unique distributions (happy to explain offline)
   How to characterize PBE? Define a "well-behaved" aux game, show aux PBE $\overset{\text{induce}}{\mapsto}$ actual PBE

Main Results & Takeaway

For resource allocation without money & without dist info...



Technical Ingredients

- **Future Punishment**
- **Adaptive Audits** ($\mathcal{O}(1)$ regret via $\widetilde{\mathcal{O}}(1)$ audits)
- **Learn via Flagging** ("condition on" argument is problematic when strategic)
- **Auxiliary Games** (revelation principle is inapplicable w/o dist info)

Thank you!

Paper link: `https://arxiv.org/abs/2502.08412`

References

[ABDVVW22] Andres Alban, Philippe Blaettchen, Harwin De Vries, and Luk N Van Wassenhove. Resource allocation with sigmoidal demands: Mobile healthcare units and service adoption. *Manufacturing & Service Operations Management*, 24(6):2944–2961, 2022.

[BGS19] Santiago R Balseiro, Huseyin Gurkan, and Peng Sun. Multiagent mechanism design without money. *Operations Research*, 67(5):1417–1436, 2019.

[BJ24] Moise Blanchard and Patrick Jaillet. Near-optimal mechanisms for resource allocation without monetary transfers. *arXiv preprint arXiv:2408.10066*, 2024.

[Cla71] Edward H Clarke. Multipart pricing of public goods. *Public choice*, pages 17–33, 1971.

[GBI21] Artur Gorokh, Siddhartha Banerjee, and Krishnamurthy Iyer. From monetary to nonmonetary mechanism design via artificial currencies. *Mathematics of Operations Research*, 46(3):835–855, 2021.

[Gro73] Theodore Groves. Incentives in teams. *Econometrica: Journal of the Econometric Society*, pages 617–631, 1973.

[Pre17] Canice Prendergast. How food banks use markets to feed the poor. *Journal of Economic Perspectives*, 31(4):145–162, 2017.

[Pre22] Canice Prendergast. The allocation of food to food banks. *Journal of Political Economy*, 130(8):1993–2017, 2022.

[PSMST22] Sebastian Perez-Salazar, Ishai Menache, Mohit Singh, and Alejandro Toriello. Dynamic resource allocation in the cloud with near-optimal efficiency. *Operations Research*, 70(4):2517–2537, 2022.

[PSÜY24] Parag A Pathak, Tayfun Sönmez, M Utku Ünver, and M Bumin Yenmez. Fair allocation of vaccines, ventilators and antiviral treatments: Leaving no ethical value behind in healthcare rationing. *Management Science*, 70(6):3999–4036, 2024.

[Vic61] William Vickrey. Counterspeculation, auctions, and competitive sealed tenders. *The Journal of finance*, 16(1):8–37, 1961.

[YBP23] Xuecheng Yin, İ Esra Büyüktahtakın, and Bhumi P Patel. Covid-19: Data-driven optimal allocation of ventilator supply under uncertainty and risk. *European journal of operational research*, 304(1):255–275, 2023.