Socially optimal allocation of ATM resources via truthful market-based mechanisms

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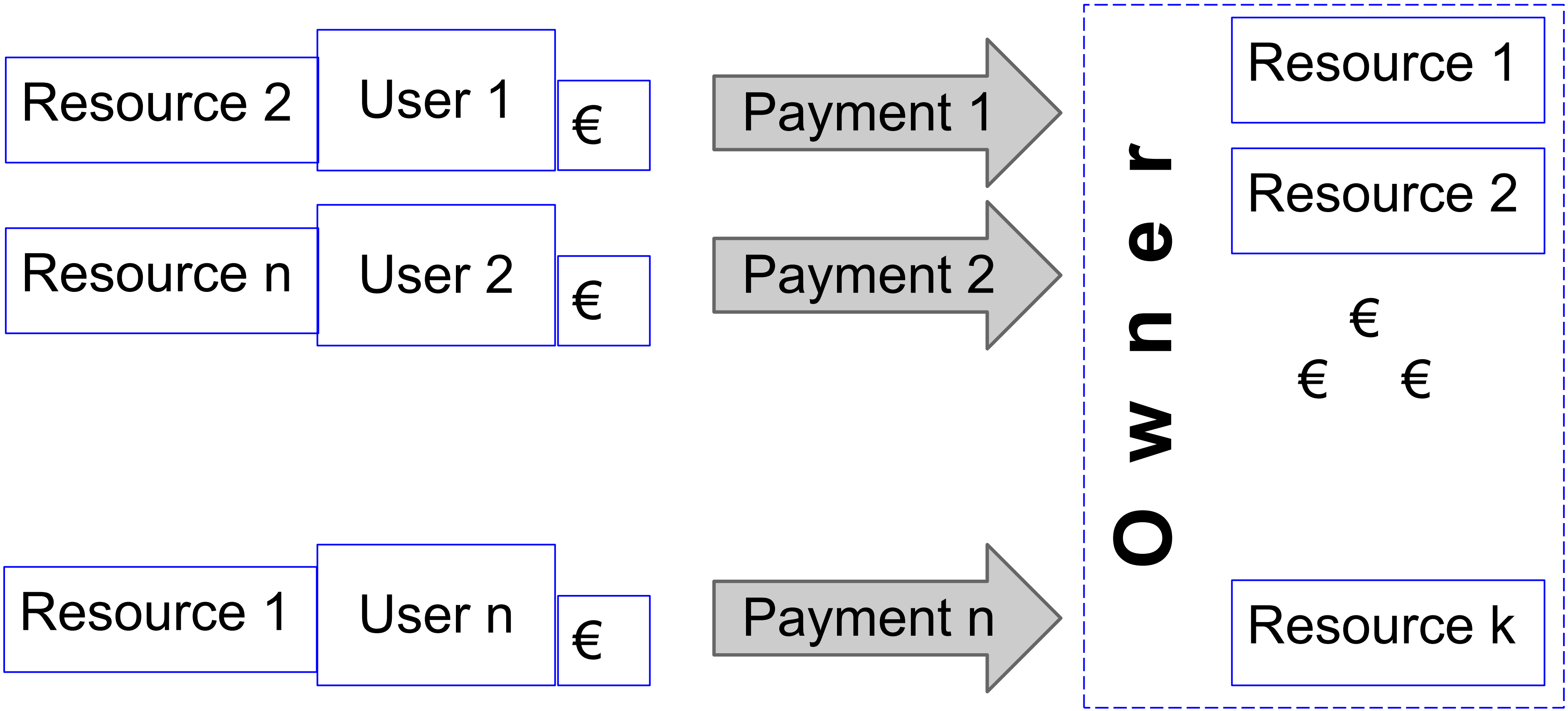
Valentin Polishchuk

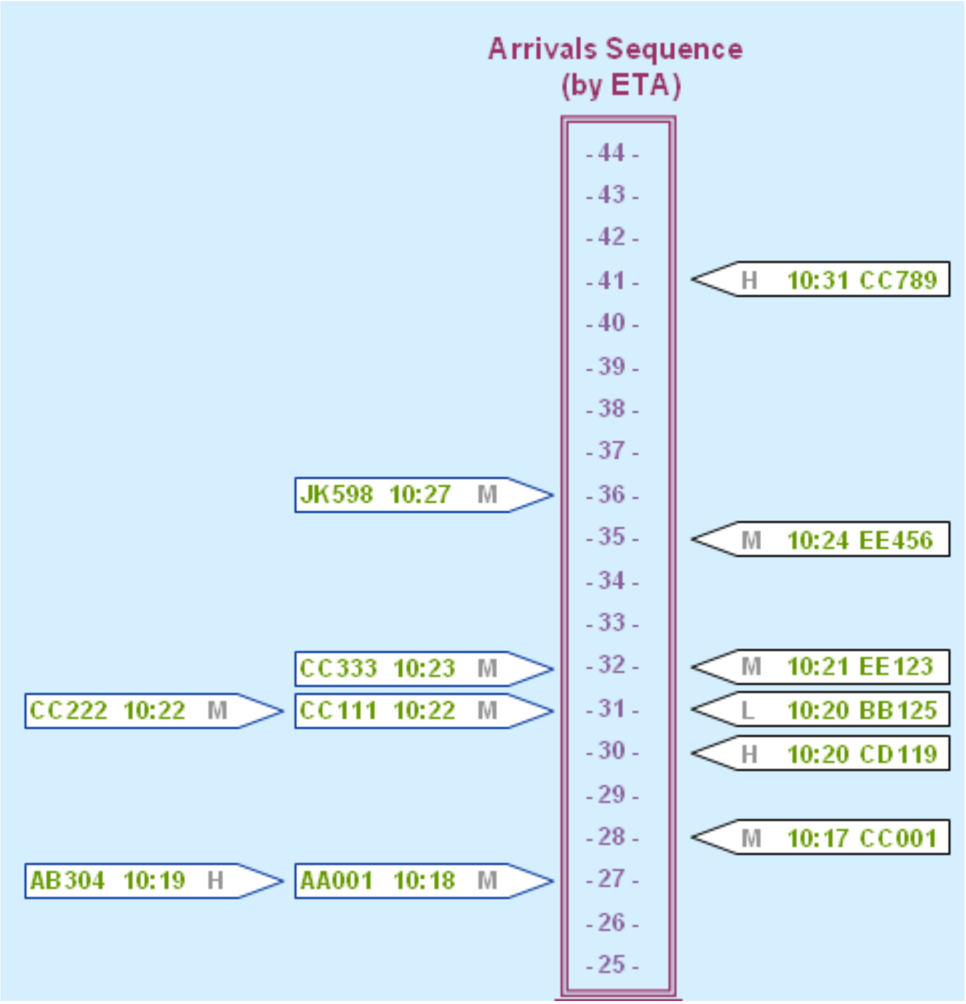
Market mechanism



Market rules?

Example: slot allocation

[Castelli, Pellegrini, Pesenti, Ranieri 2009--2012]



http://www.euro-cdm.org/library_scenarios.php

Example: conference program

SESARWPE
LONG TERM AND INNOVATIVE RESEARCH

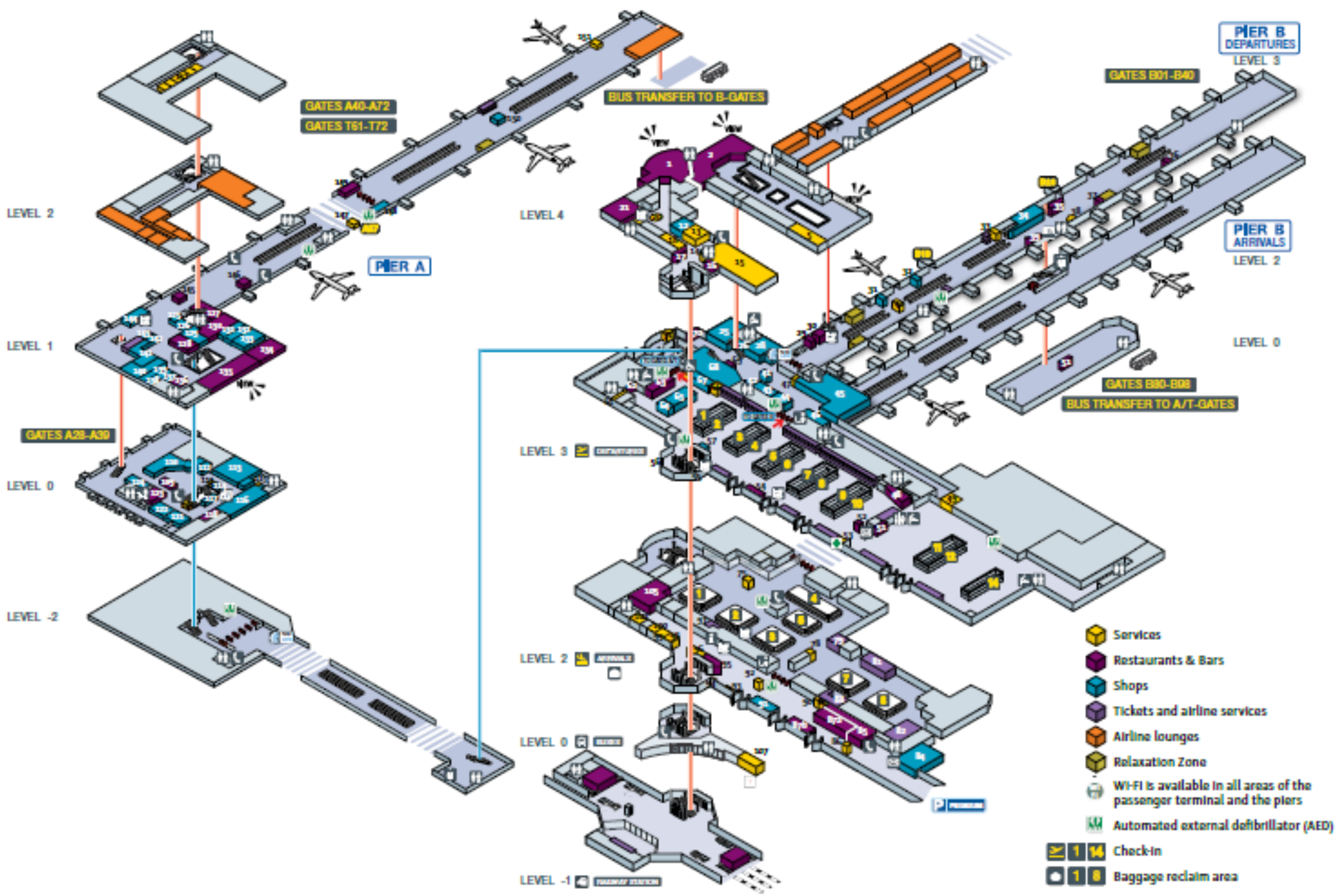
Second SESAR Innovation Days
27th - 29th November 2012
Braunschweig, Germany

Day 2: 28th November 2012

8:45 – 9:45	Keynote 2 *Otto Gies, EADS*	
9:45 – 10:15	Liabilities and Automation in Aviation *Giuseppe Contissa, Giovanni Sartor, European University Institute*	
10:15 – 10:30	Poster Teaser Session 2	
10:30 – 11:00	Coffee	
11:00 – 12:30	Trajectory Management Conflict Resolution with Time Constraints in Trajectory-Based Arrival Management *Damian Rivas, University of Seville* Examples of Supervisory Interaction with Route Optimizers *Oliver Turnbull, University of Bristol* Flight Trial Evaluation Of Automated Paired Approaches Onto Closely Spaced Parallel Runways *Bernd Korn, DLR*	Human Factors Remote Towers: Videopanorama Frame Rate Requirements Derived from Visual Discrimination of Deceleration during Simulated Aircraft Landing *Norbert Fürstenau, DLR* Introduction of a more Automated Environment in En-Route ATC *Jean-Paul Imbert, ENAC* Applying the Resilience Engineering and Management Perspective to Problems of Human Alarm Interaction in ATM *Simone Rozzi, Middlesex University*
12:30 – 13:30	Lunch	
	Flow Management Optimization and Prioritisation of Flows	Safety and Security Agent-Based Modelling of Hazards in ATM

http://sesarinnovationdays.eu

Example: shop locations



http://www.brusselsairport.be/en/passngr/at_the_airport/airport_map/

Fundamental questions

Bid--allocate--pay mechanisms:

- What info to solicit from users?
- How to ensure the users submit true info?
- How to allocate resources?
- How much to charge the users?

Mechanism: desirable properties

- Social Optimality (SO):
  allocation maximizes benefit to the society
- Incentive Compatibility (IC), or Truthfulness:
  no user benefits from lying
- Individual Rationality (IR):
  each user gets a non-negative utility
- Budget Balance (BB):
  the resource owner's net profit is 0

[Myerson and Satterthwaite, 1983]

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No mechanism can be SO, IC, IR, BB

Castelli, Pellegrini, Pesenti, Ranieri '09-'12

vs

this paper

	SO	IC	IR	BB
Earlier work	*Possibly*	*No*	***Yes***	***Yes***
This paper	***Yes***	***Yes***	*Possibly*	*No*

Definitions

Valuation $v_i(a)$

Users: 1, 2 , ..., i , ... , n
A: set of all allocations

$$v_i : A \to R$$

$v_i(a)$: How much user i likes allocation a

- number (in Euros)
- monetary value
- can be negative

Selfish rational (envy-free) user

Most often:

$v_i(a)$ depends only on $a(i)$

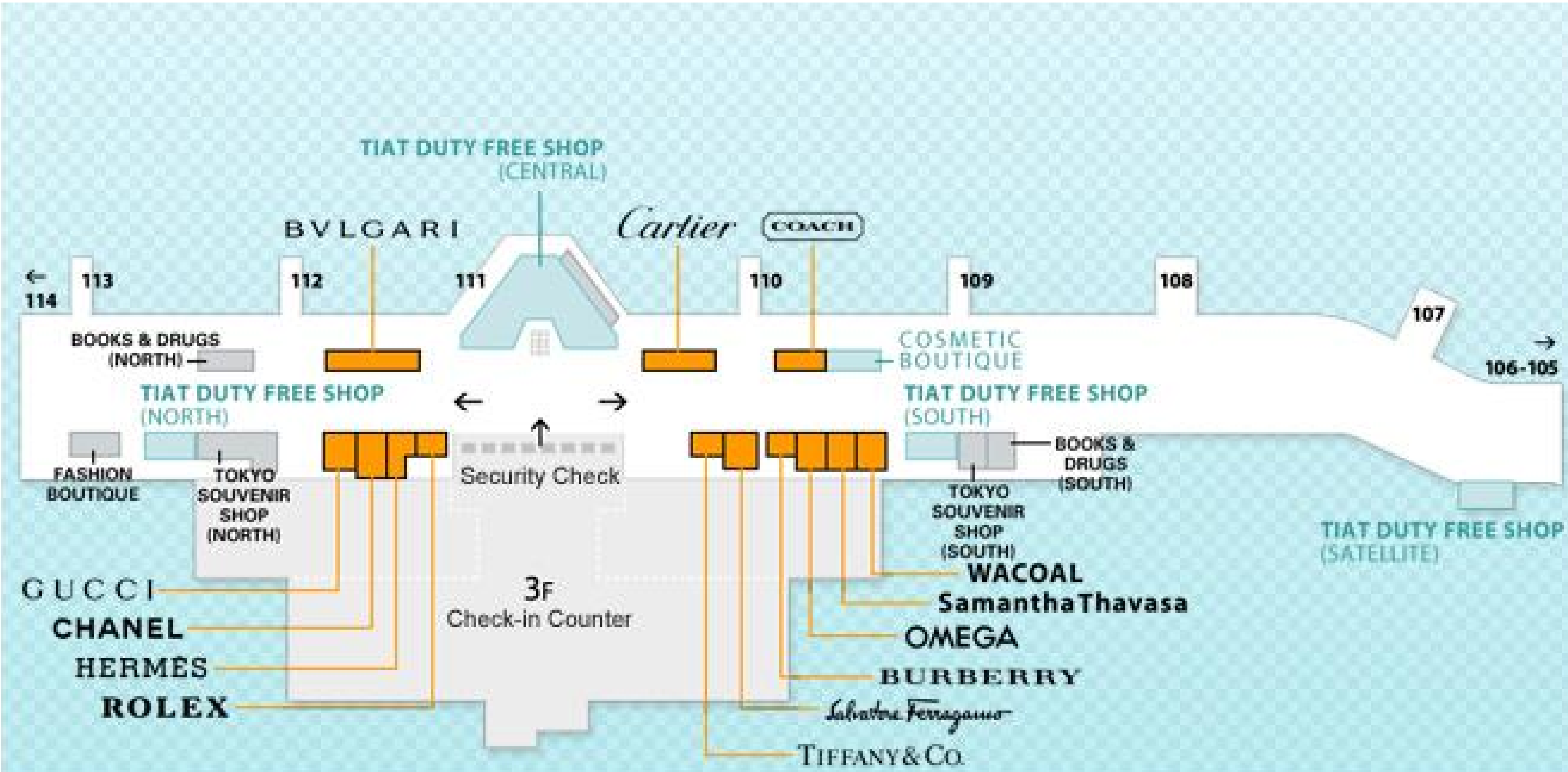
does not depend on what others get

Sometimes:

$v_i(a)$ depends on not only on $a(i)$

but also on what others got

Valuation depends on others' allocation



https://duty-free-japan.jp/haneda/en/content_shop/place_shop_airport.html

Example: conference program

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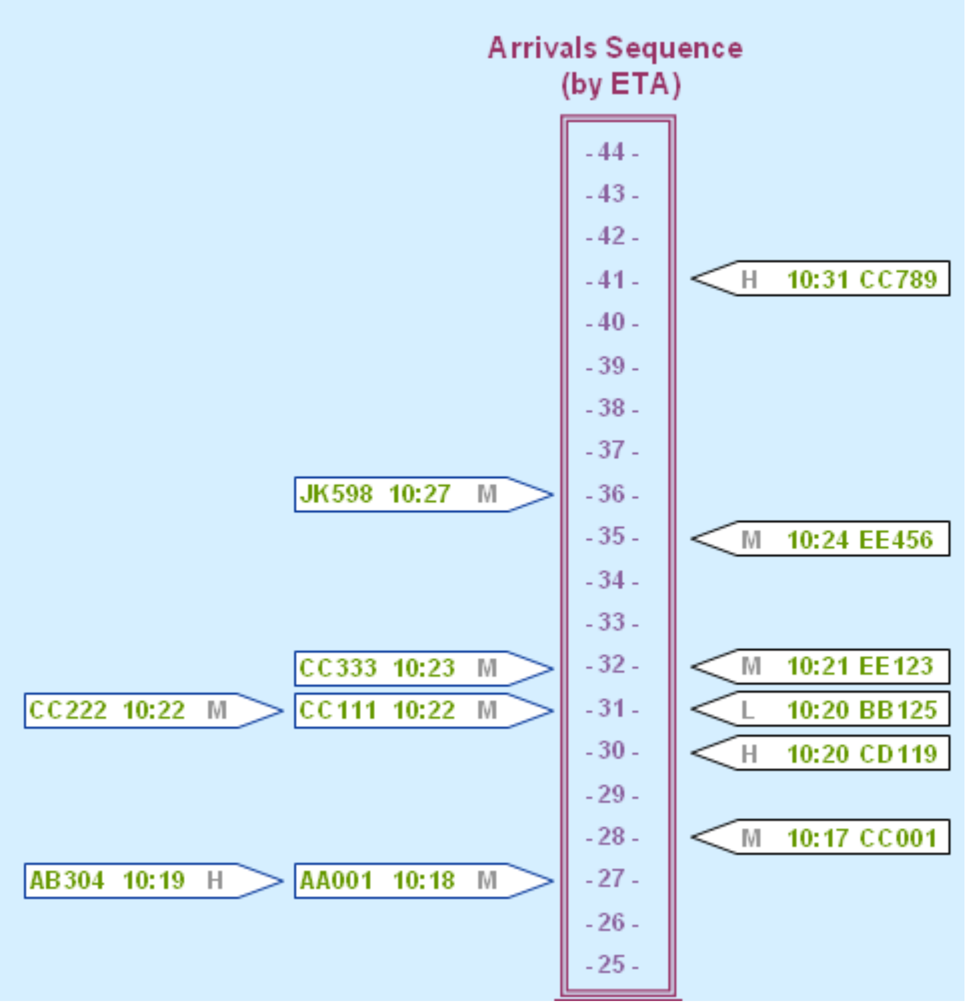
Example: slot allocation

Arrival of latest flight
connecting to
my outbound flight



http://www.euro-cdm.org/library_scenarios.php

"World" = $(v_1, v_2, \ldots, v_n)$

User i has a valuation for each outcome

User i has a function $v_i : A \to R$

User i *is* a function $v_i : A \to R$

V: the set of all "worlds", all $v = (v_1, v_2, \ldots, v_n)$

"State of the world": v in V

Mechanism: (f,p)

$f : V \rightarrow A$, social choice $f(v)$

$p : V \rightarrow R^n$, payments $p(v) = (p_1, p_2, \ldots, p_n)$

$p_i < 0$ -- mechanism pays to i

For any user:

utility = valuation(allocation) - payment

$v_i(f(v)) - p_i(v)$

Social Optimality (SO)

f chooses socially optimal allocation

$$\sum_i v_i(f(v)) \quad = \quad \max_{a \text{ in } A} \sum_i v_i(a)$$

Allocations: good and not-so-good
Social welfare -- measure of "goodness"

Incentive Compatibility (IC)

No incentive to lie to mechanism

For every i
for any two "worlds":

$$v' = (v'_1, v'_2, \dots, v'_{i-1}, v'_i, v'_{i+1}, \dots, v_n)$$
$$v^* = (v'_1, v'_2, \dots, v'_{i-1}, v_i, v'_{i+1}, \dots, v'_n)$$

$$v_i(f(v^*)) - p_i(v^*) \quad \geq \quad v_i(f(v')) - p_i(v')$$

Example:
slot assignment, linear valuations

Users		Slots
1	——	1
2	——	2
...		...
.		.

$v_i(s) = C_i - w_i * s$

$w_1 > w_2 > \dots > w_n$

Socially optimal

$p_1 = 0$

$p_2 = 0,\ p_3 = 0,\ \dots,\ p_n = 0$

$p_1 = 1000000$

$p_2 = 0,\ p_3 = 0,\ \dots,\ p_n = 0$

Vickrey--Clarke--Groves (VCG)

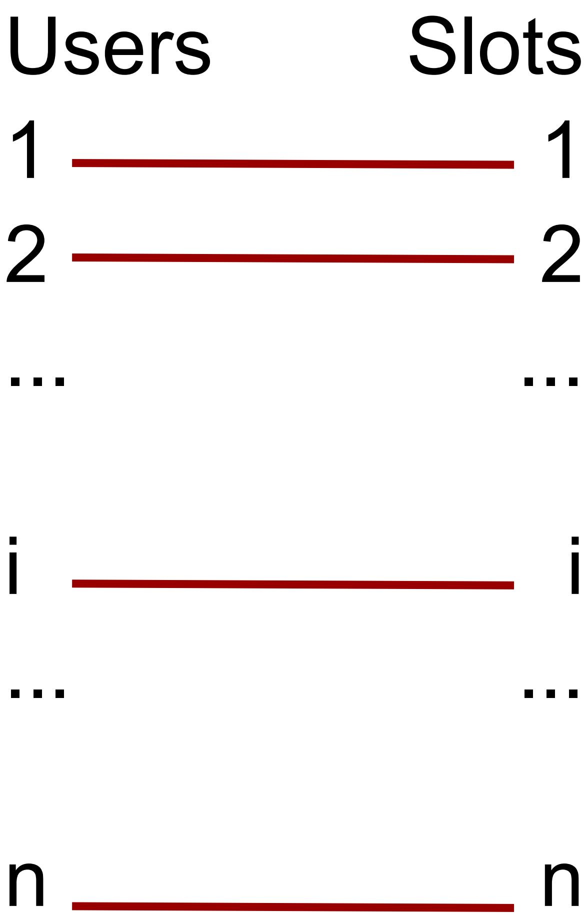
f is SO: $\sum_i v_i(f(v)) = \max_{a \text{ in } A} \sum_i v_i(a)$

$p_i(v) = \max_{a \text{ in } A} \sum_{j \neq i} v_j(a) - \sum_{j \neq i} v_j(f(v))$

= "harm" of i to the society

Theorem [Vickrey'61, Clarke'71, Groves'73]:
VCG is SO, IC and IR

Example:
slot assignment, linear valuations



$$v_i(s) = C_i - w_i * s$$

$$w_1 > w_2 > \ldots > w_n$$

$$f(v) = a \text{ with } a(i) = i$$

$$v_i(f(v)) = C_i - w_i * i$$

$$\sum_i v_i(f(v)) = \sum_i (C_i - w_i * i)$$

Example:
slot assignment, linear valuations

$$p_i = \max_{a \text{ in } A} \sum_{j \neq i} v_j(a) \quad - \quad \sum_{j \neq i} v_j(f(v))$$

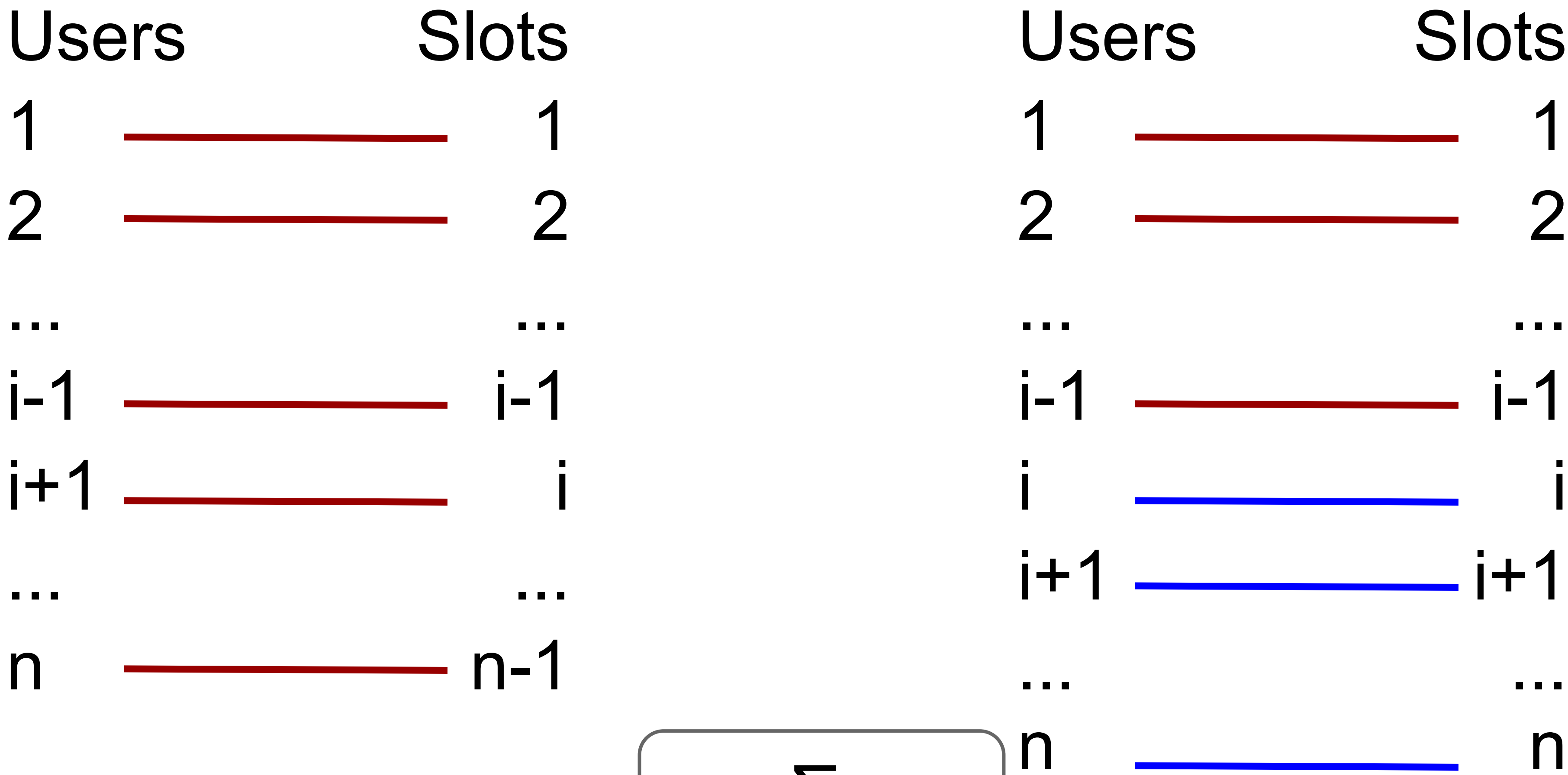
Users	1, 2 , ... , i-1, i+1 ,..., n
get slots	1, 2 , ... , i-1, i ,..., n-1

$$\max_{a \text{ in } A} \sum_{j \neq i} v_j(a) = \sum_{j<i} (C_j - w_j * j) + \sum_{j>i} (C_j - w_j * (j-1))$$

$$\sum_{j \neq i} v_j(f(v)) = \sum_{j<i} (C_j - w_j * j) + \sum_{j>i} (C_j - w_j * j)$$

$$\boxed{p_i = \sum_{j>i} w_j}$$

Example:
slot assignment, linear valuations



$$p_i = \sum_{j>i} w_j$$

This paper
vs
Castelli, Pellegrini, Pesenti, Ranieri '09-'12

	SO	IC	IR	BB
Earlier work	*Possibly*	*No*	***Yes***	***Yes***
This paper	***Yes***	***Yes***	*Possibly*	*No*

William Spencer Vickrey (1914 – 1996)

Nobel prize 1996

Bertil Näslund

Royal Swedish Academy:

"Vickrey's contributions in this area have had important practical consequences, for example regarding the design of auctions of government securities, **air traffic concessions**, and band spectrum licenses."

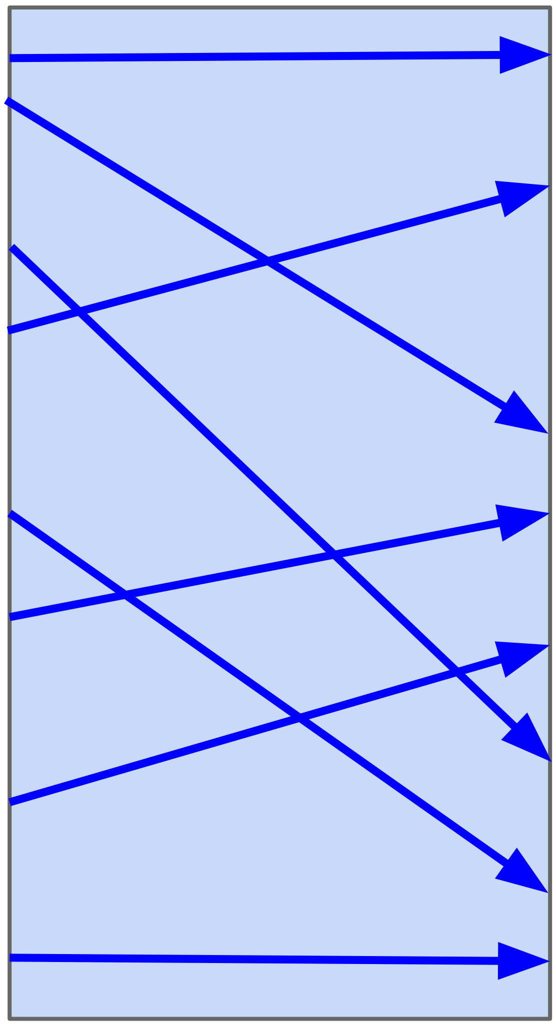
http://www.nobelprize.org/nobel_prizes/economics/laureates/1996/presentation-speech.html

Mechanism design for ATM: open problems, challenges

Theory vs applications

- Computational challenges
    - how to find allocation and prices efficiently
- Uncertainty
    - dynamic and stochastic nature of ATM
- Other objectives
    - besides SO
- Other properties
    - besides SO, IC, IR, BB
- Privacy
    - valuation, other private info
- Owner's profit
    - maximization, issues with monopoly

Other settings



Implementation?

Legislative responsibility: Auctions for what ATM resources?

LFV

swedavia
SWEDISH AIRPORTS

Monetization of preferences

European airline delay cost reference values

University of Westminster for EUROCONTROL

[Cook, Tanner, Anderson '04. Evaluating the True Cost to Airlines of One Minute of Airborne or Ground Delay]

Or airlines determine costs themselves?

Objective function:

total delay or max delay?

Who is the user?

Earlier work: per-flight view
Business entity: airline
Passengers? POEM
Note: users are active; players

Questions, questions...

Questions?