Game Theory *and Practice* for Society and Economy

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Doctoral Consortium - AI*IA 2014

AI and Society?

SOCIETY AND ECONOMY

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ARTIFICIAL INTELLIGENCE

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GAME THEORY

ARTIFICIAL INTELLIGENCE

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GAME THEORY

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ARTIFICIAL INTELLIGENCE

Apologia di un matematico, 1940:

Non ho mai fatto nulla di «utile». Nessuna mia scoperta ha contribuito, e verosimilmente mai lo farà, ad apportare il benché minimo miglioramento, diretto o indiretto, al benessere dell'umanità. [...] Giudicato dal punto di vista della rilevanza pratica, il valore della mia vita matematica è nullo. [...] La sola difesa della mia vita è questa: Ho aggiunto qualcosa al sapere e ho aiutato altri ad aumentarlo ancora; il valore dei miei contributi si differenzia soltanto in grado, e non in natura, dalle creazioni dei grandi matematici, o di tutti gli altri artisti, grandi e piccoli, che hanno lasciato qualche traccia dietro di loro.

AI and Society?

GAME THEORY

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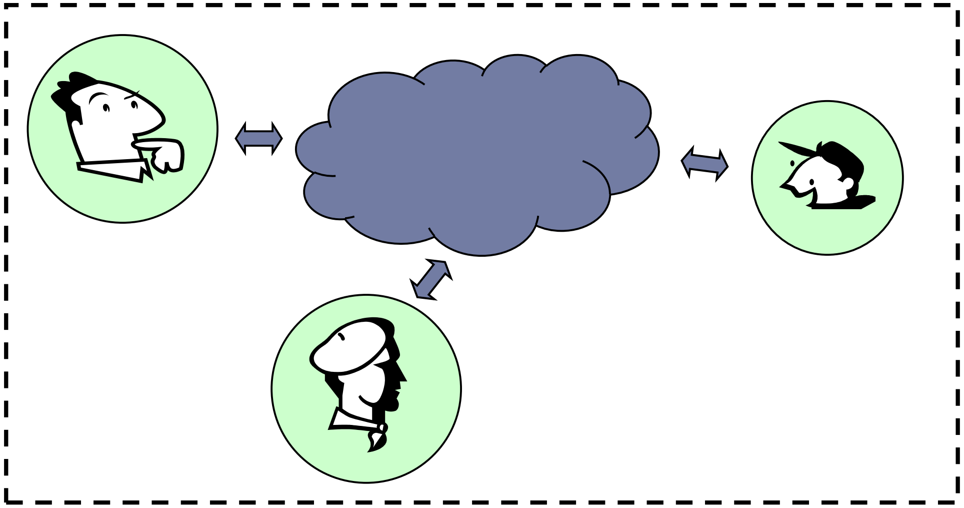
Game Theory

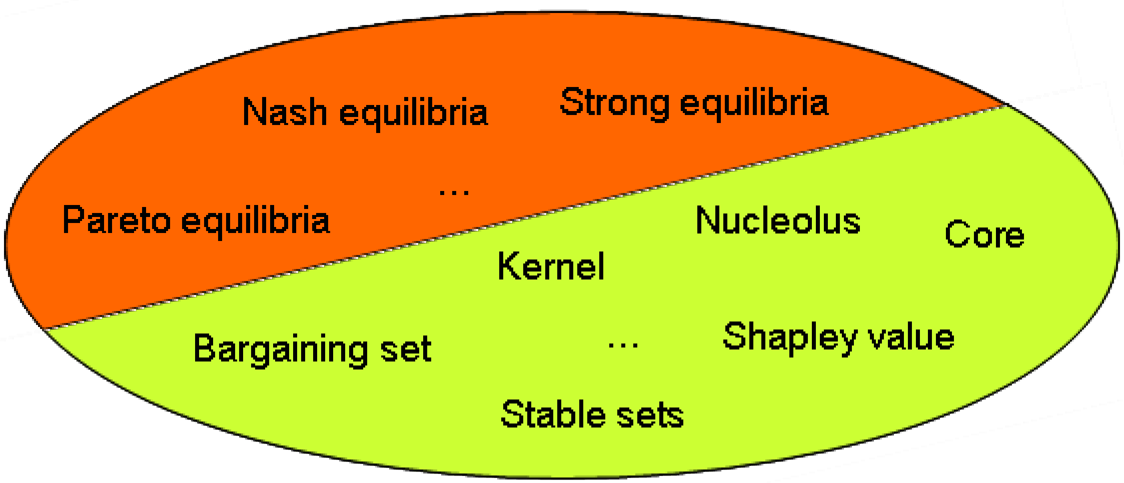


Each player:

- Has a **goal** to be achieved
- Has a set of possible **actions**
- **Interacts** with other players
- Is **rational**

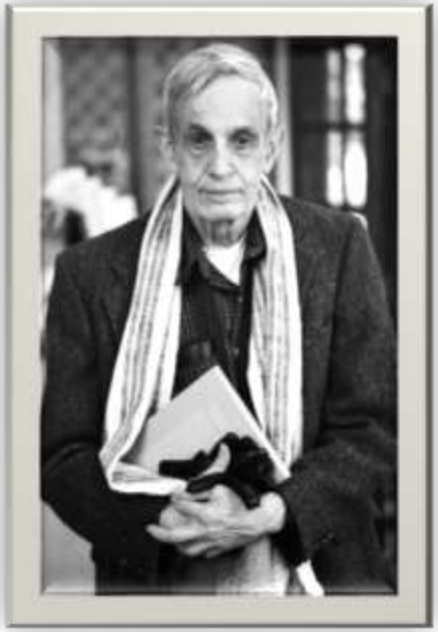
Which actions have to be performed?

Solution Concepts



Two Perspectives

- **Strategic Games**
  - Agents are selfish interested



JOHN NASH

- **Coalitional Games**
  - Agents can collaborate

JOHN VON NEUMANN

STRATEGIC GAMES

Non-Cooperative Games

Payoff maximization problem

Each player:

- Has a **goal** to be achieved
- Has a set of possible **actions**
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Bob	John goes *out*	John stays at *home*
out	2	0
home	0	1

John	Bob goes *out*	Bob stays at *home*
out	1	1
home	0	0

Non-Cooperative Games

Payoff maximization problem

Nash equilibria

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Non-Cooperative Games

Payoff maximization problem

Nash equilibria

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***pure* Nash equilibria**

Every game admits a *mixed* Nash equilibrium,

- **where players chose their strategies according to probability distributions**

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Game Representations

- **Players:**
  - Maria, Francesco
- **Choices:**
  - movie, opera

If 2 players, then size = 2^2

Maria	Francesco, *movie*	Francesco, *opera*
movie	2	0
opera	0	1

Game Representations

- **Players:**
  - Maria, Francesco, Paola
- **Choices:**
  - movie, opera

If 2 players, then size = 2^2

If 3 players, then size = 2^3

Maria	F_{movie} *and* P_{movie}	F_{movie} *and* P_{opera}	F_{opera} *and* P_{movie}	F_{opera} *and* P_{opera}
movie	2	0	2	1
opera	0	1	2	2

Game Representations

- **Players:**
  - Maria, Francesco, Paola, Roberto, and Giorgio
- **Choices:**
  - movie, opera

If 2 players, then size = 2^2

If 3 players, then size = 2^3

…

If N players, then size = 2^N

Maria	F_{movie} *and* P_{movie} *and* R_{movie} *and* G_{movie}	…………………………..		
movie	2	……..	……..	……..
opera	0	……..	……..	……..

Game Representations

- **Game Representation**
  - Tables
  - Arbitrary Functions

Maria	F_{movie} *and* P_{movie}	*and* R_{movie} *and* G_{movie}	…………………………..	
movie	2	……..	……..	……..
opera	0	……..	……..	……..

Game Representations

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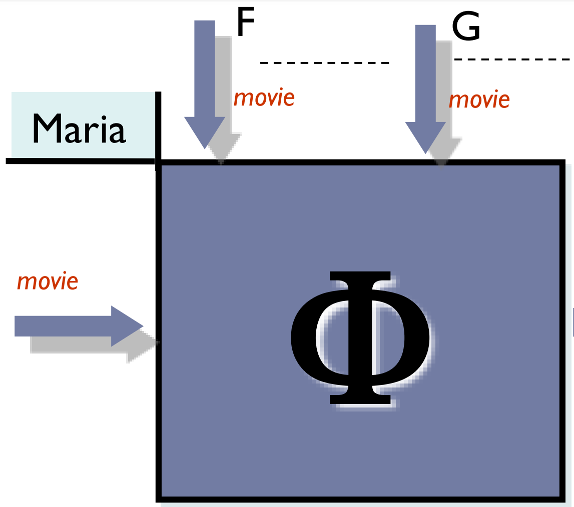

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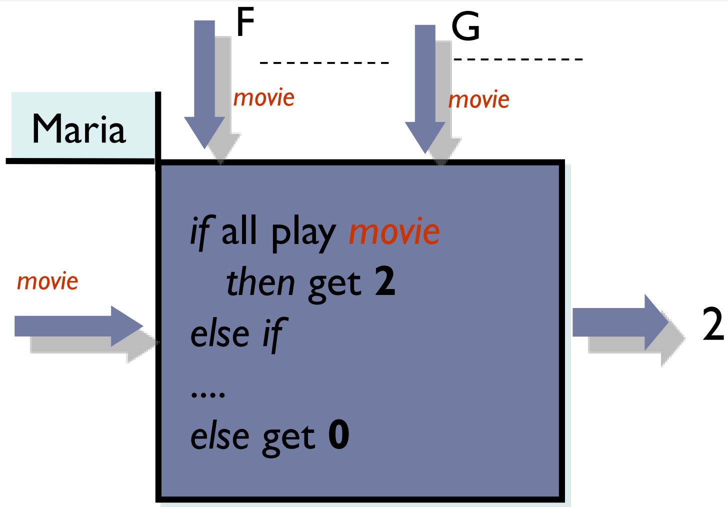
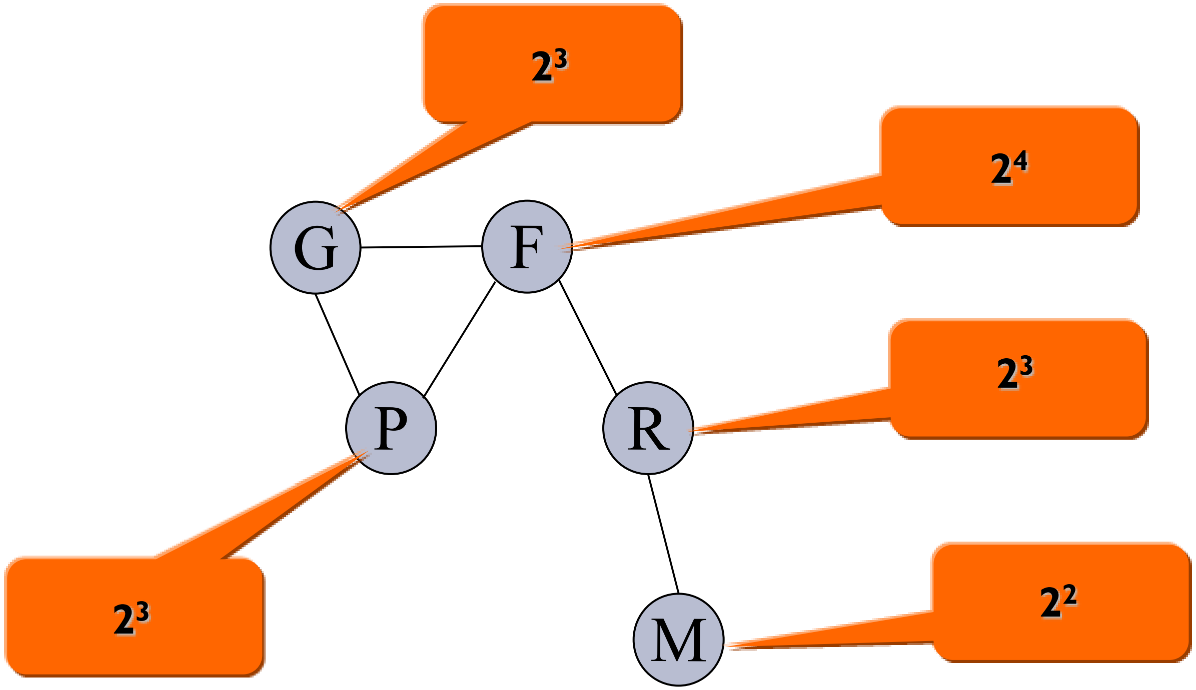


Maria	F_{movie} *and* P_{movie} *and* R_{movie} *and* G_{movie}		…………………………..	
movie	2	……..	……..	……..
opera	0	……..	……..	……..

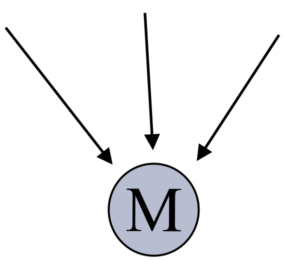
Game Representations

- **Players:**
  - Francesco, Paola, Roberto, Giorgio, and Maria
- **Choices:**
  - movie, opera



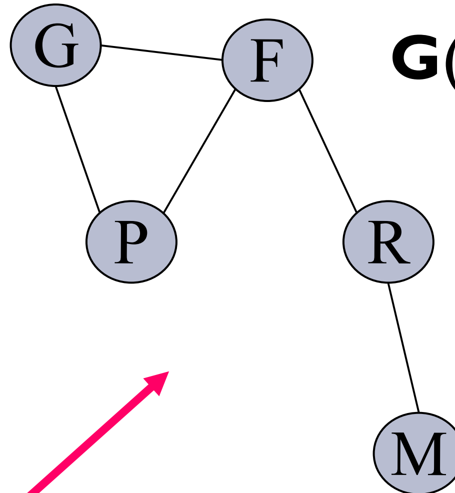
Games on Graphs

- Game Representation
  - ~~Tables~~
  - ~~Arbitrary Functions~~
- Neighborood
  - Arbitrary
  - Small (i.e., log)
  - Bounded (i.e., constant)

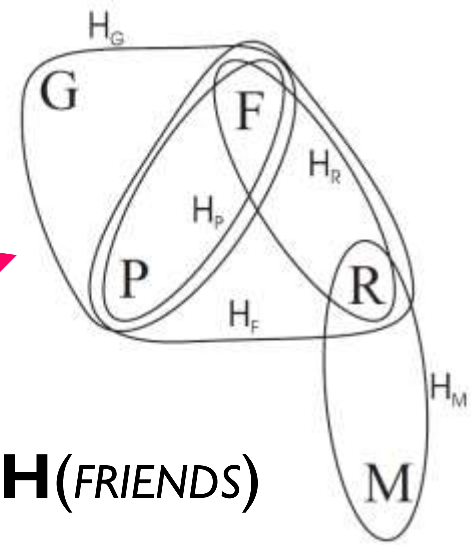


Games on Graphs

- **Game Representation**
  - ~~Tables~~
  - ~~Arbitrary Functions~~
- **Neighborood**
  - Arbitrary
  - Small (i.e., log)
  - Bounded (i.e., constant)
- **Interactions**
  - Game graph G:
    - acyclic or *bounded treewidth*
  - Game hypergraph H:
    - acyclic or *bounded hypertreewidth*



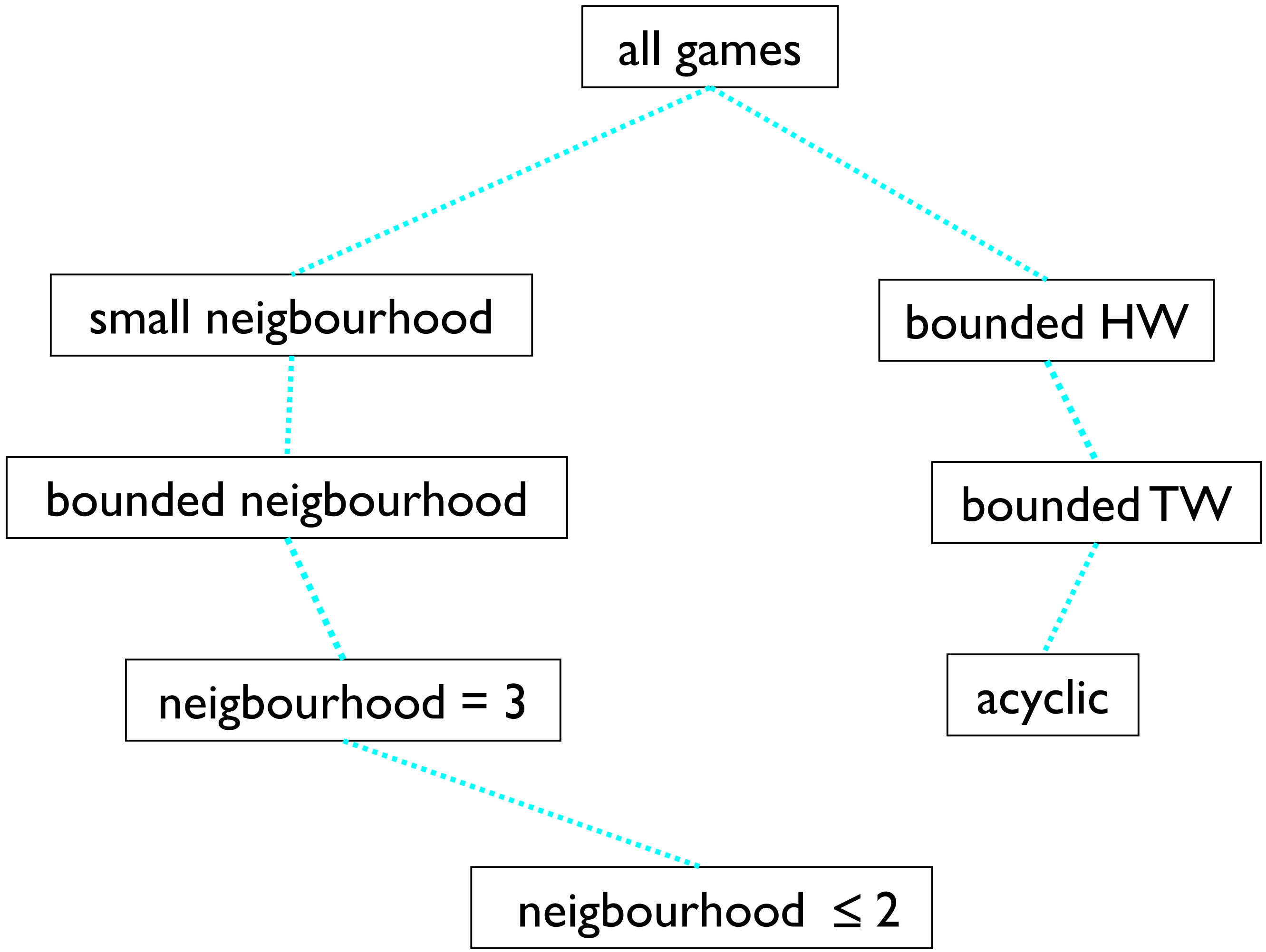
G(*FRIENDS*)



H(*FRIENDS*)

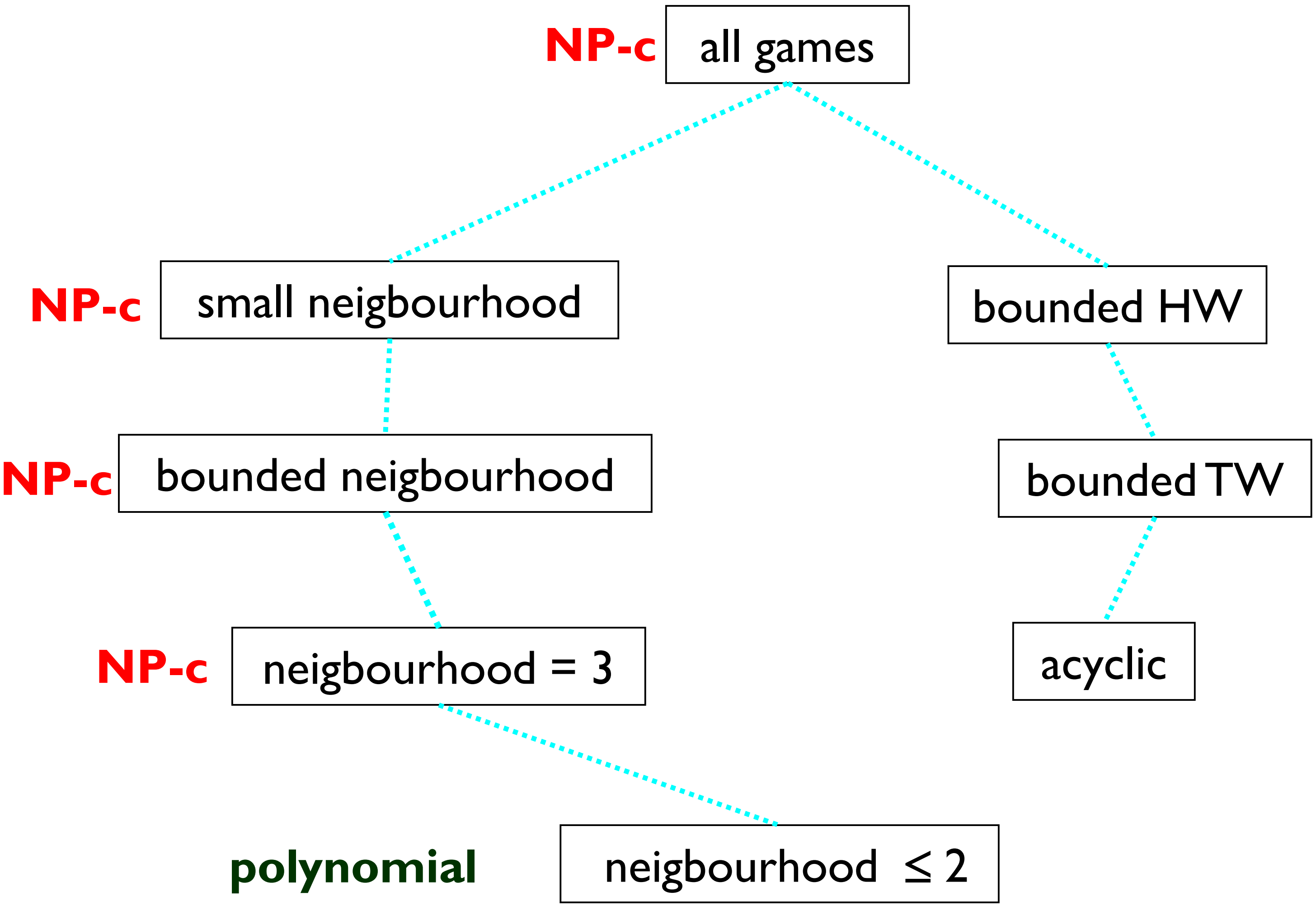
Results [GGS'05]

[G., Gottlob, Scarcello JAIR'05]



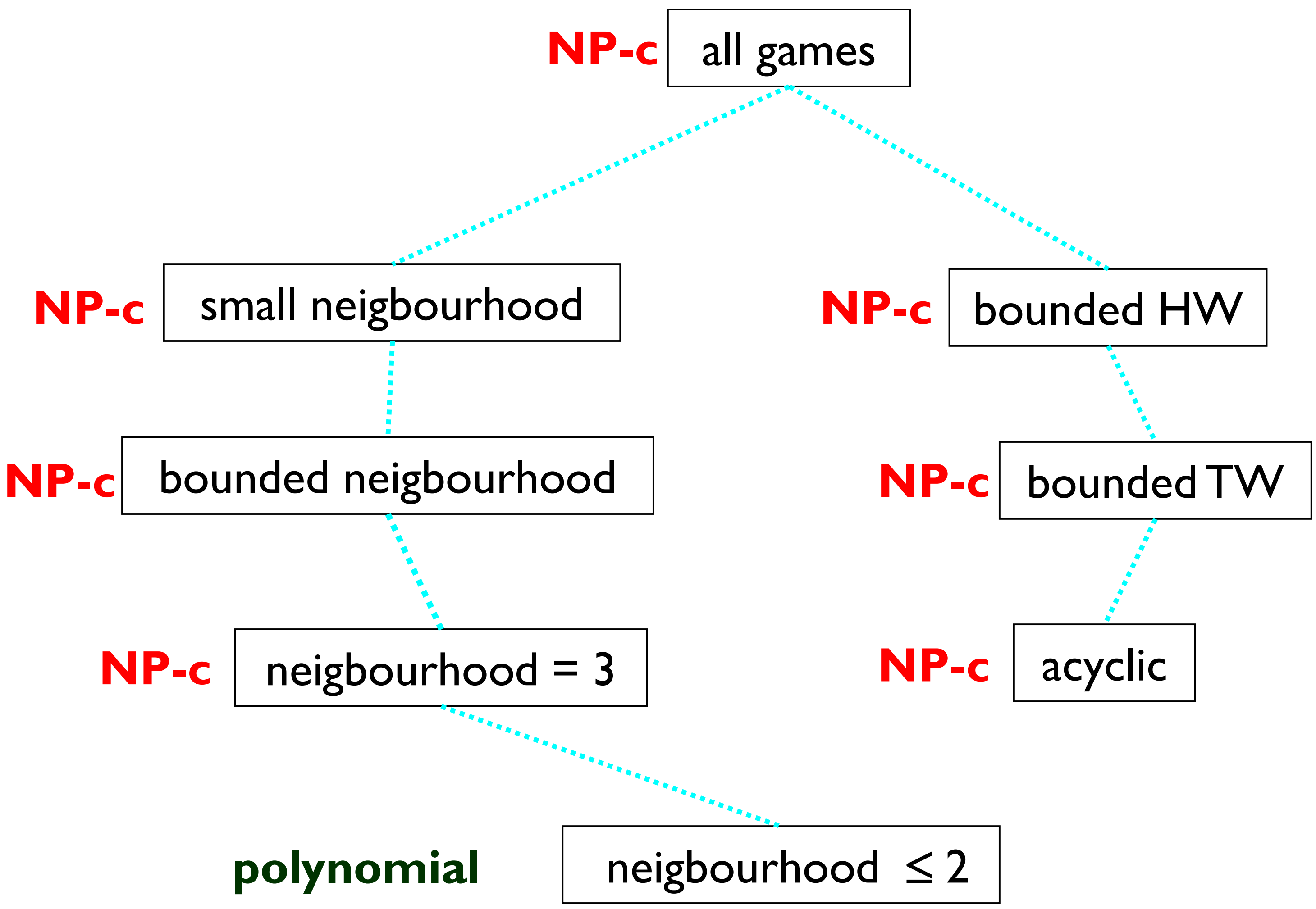
Results [GGS'05]

THE BAD NEWS:



Results [GGS'05]

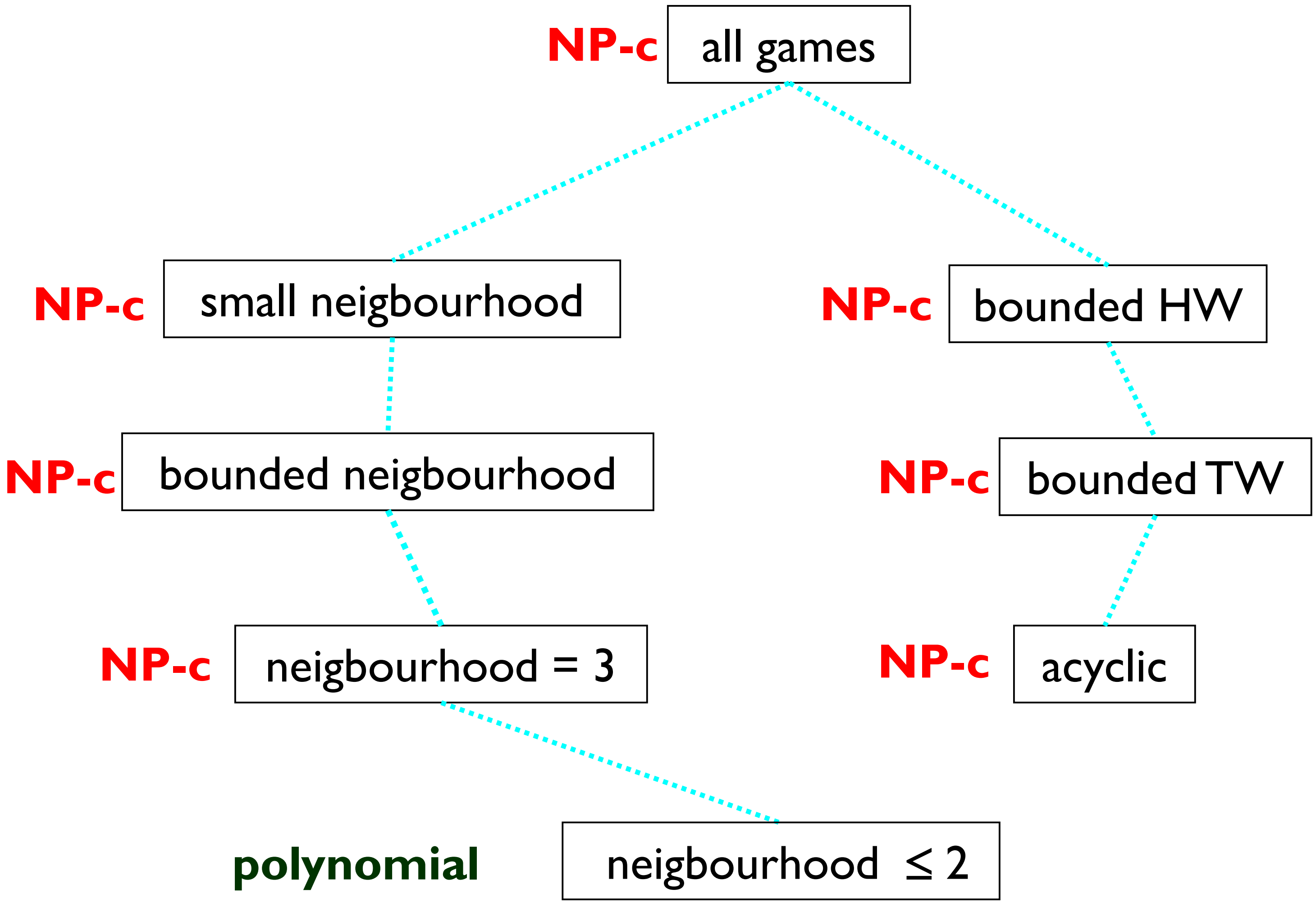
THE BAD NEWS: **FURTHER BAD NEWS:**



Results [GGS'05]

THE GOOD NEWS:

CSP techniques



Results [GGS'05]

THE GOOD NEWS:

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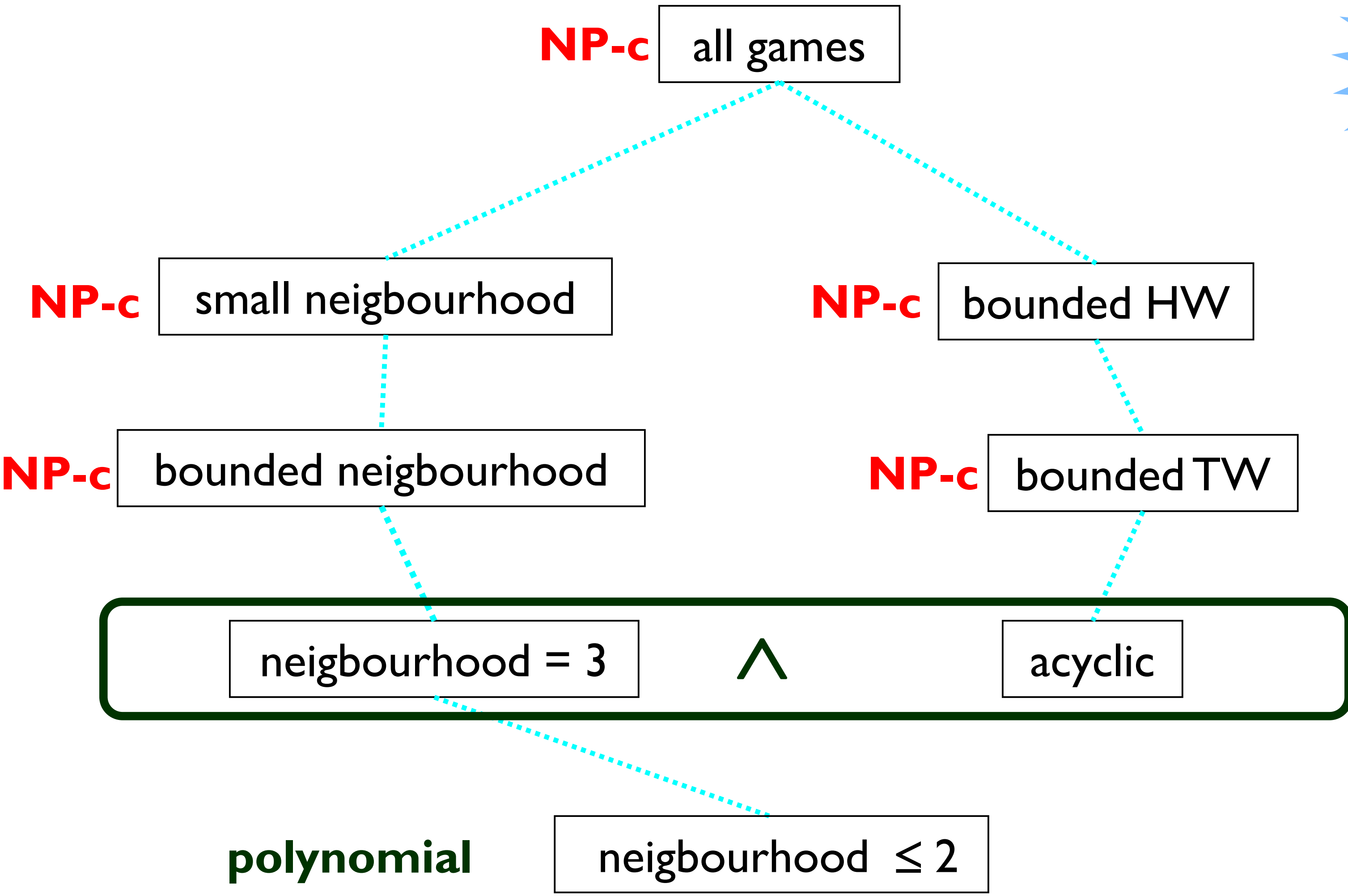

Results [GGS'05]

EVEN BETTER NEWS:

CSP techniques

NP-c all games

NP-c small neigbourhood

NP-c bounded HW

bounded neigbourhood ∧ bounded TW — **polynomial**

neigbourhood = 3 ∧ acyclic — **polynomial**

polynomial neigbourhood ≤ 2

Results [GGS'05]

THE BEST NEWS:

CSP techniques

NP-c all games

small neigbourhood ∧ bounded HW — **polynomial**

bounded neigbourhood ∧ bounded TW — **polynomial**

neigbourhood = 3 ∧ acyclic — **polynomial**

polynomial neigbourhood ≤ 2

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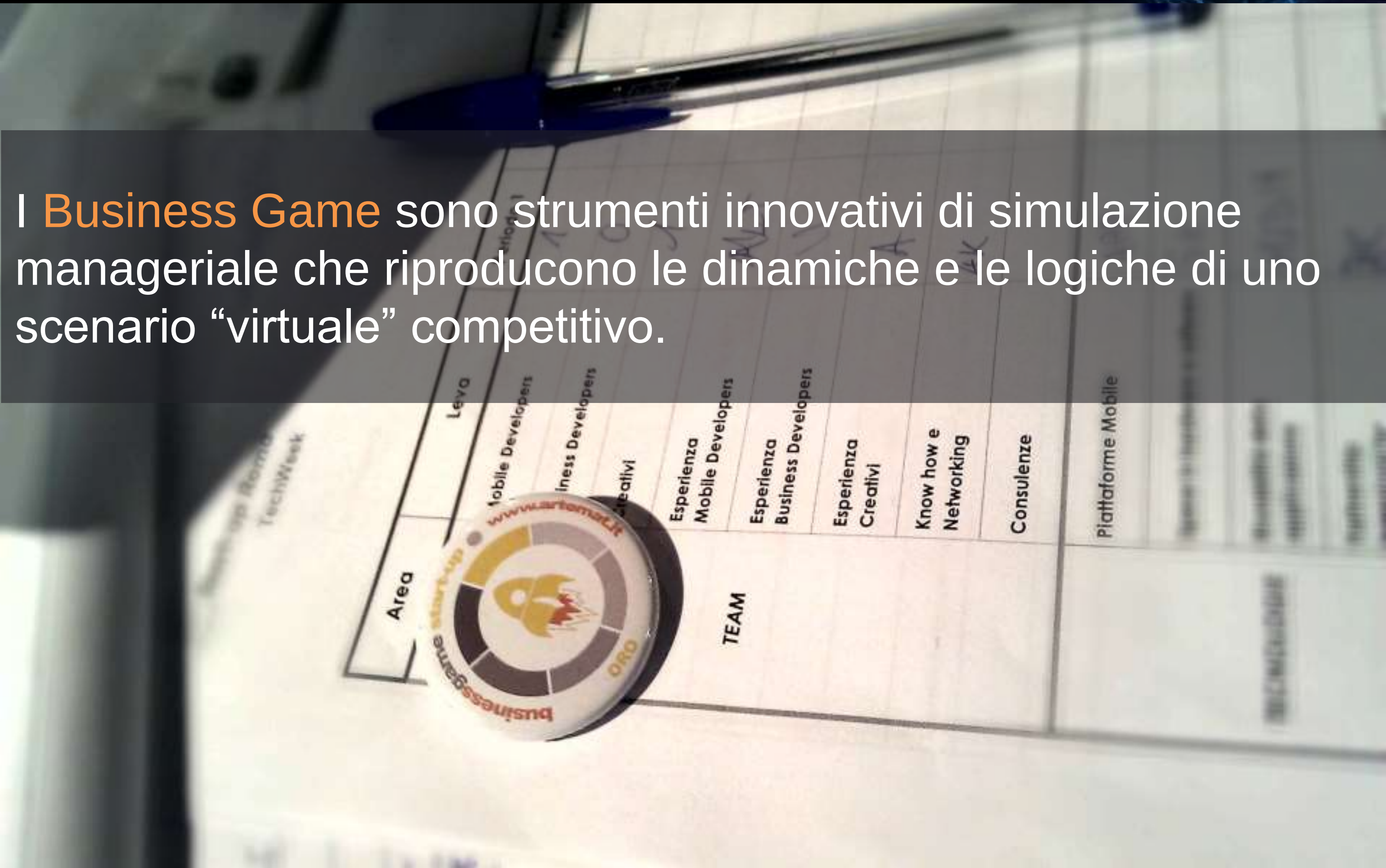
ArtéMat

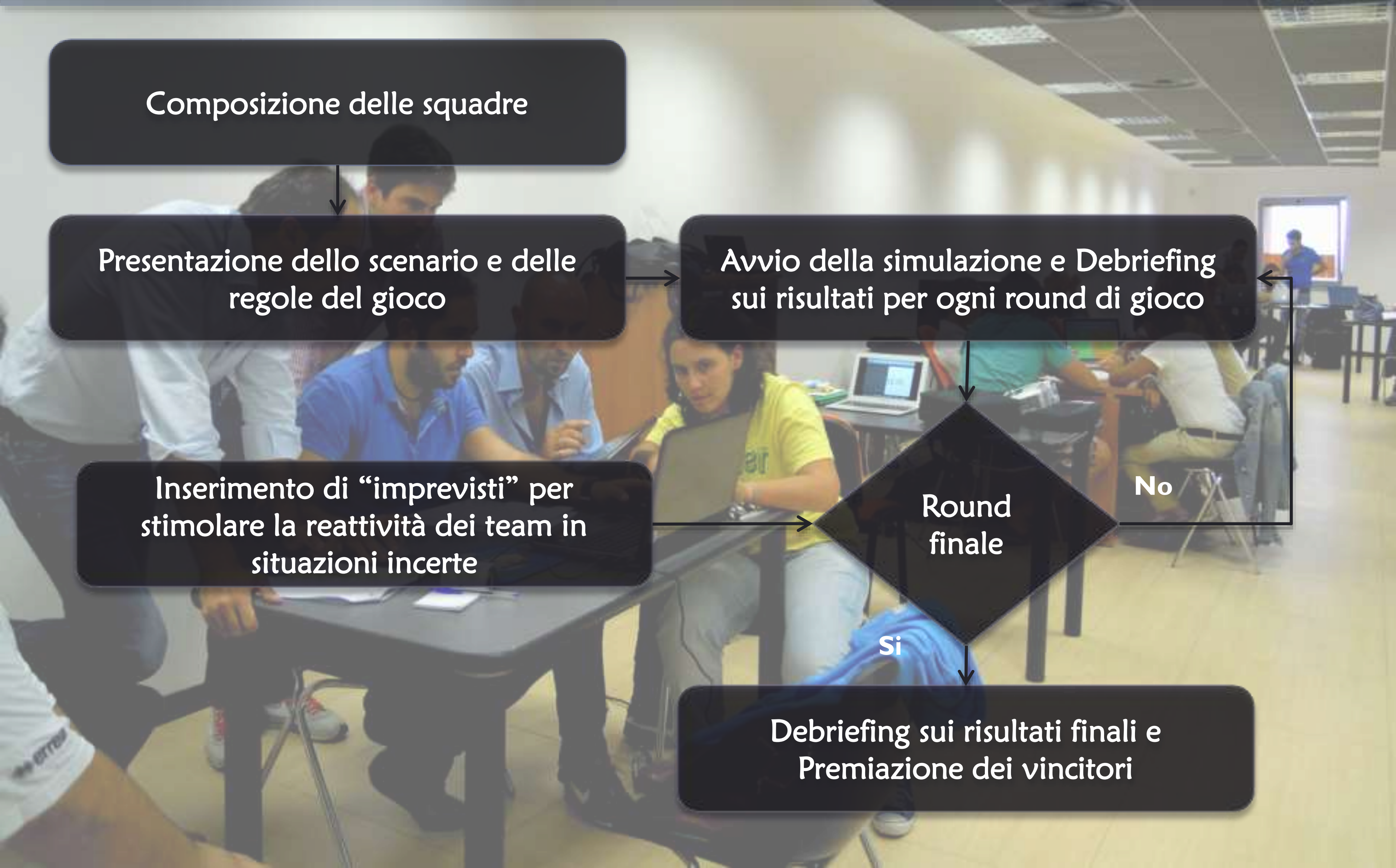
- Spinoff dell'Università della Calabria
  - Ormai da 10 anni sul mercato
  - E' una delle principali realtà imprenditoriali in Italia nell'ideazione e sviluppo di Business Simulation per la formazione manageriale ed il recruitment
  - Collabora con: Scuole di Alta Formazione Manageriale, Grandi Aziende, Università, Associazioni di Categoria, Incubatori d'impresa

Business Games

I Business Game sono strumenti innovativi di simulazione manageriale che riproducono le dinamiche e le logiche di uno scenario “virtuale” competitivo.



Funzionamento

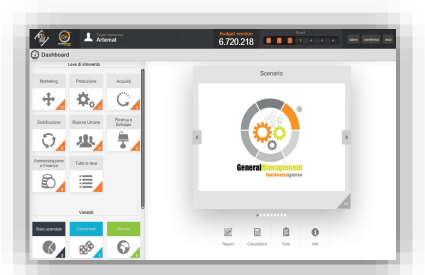


BG e AI

Analista Artémat, presso il cliente

Modello di mercato, formalizzato nel linguaggio BGL

Compilatore del modello:
- Sistema sviluppato prototipalmente presso Artémat Lab
- Oggi, completamente ingegnerizzato



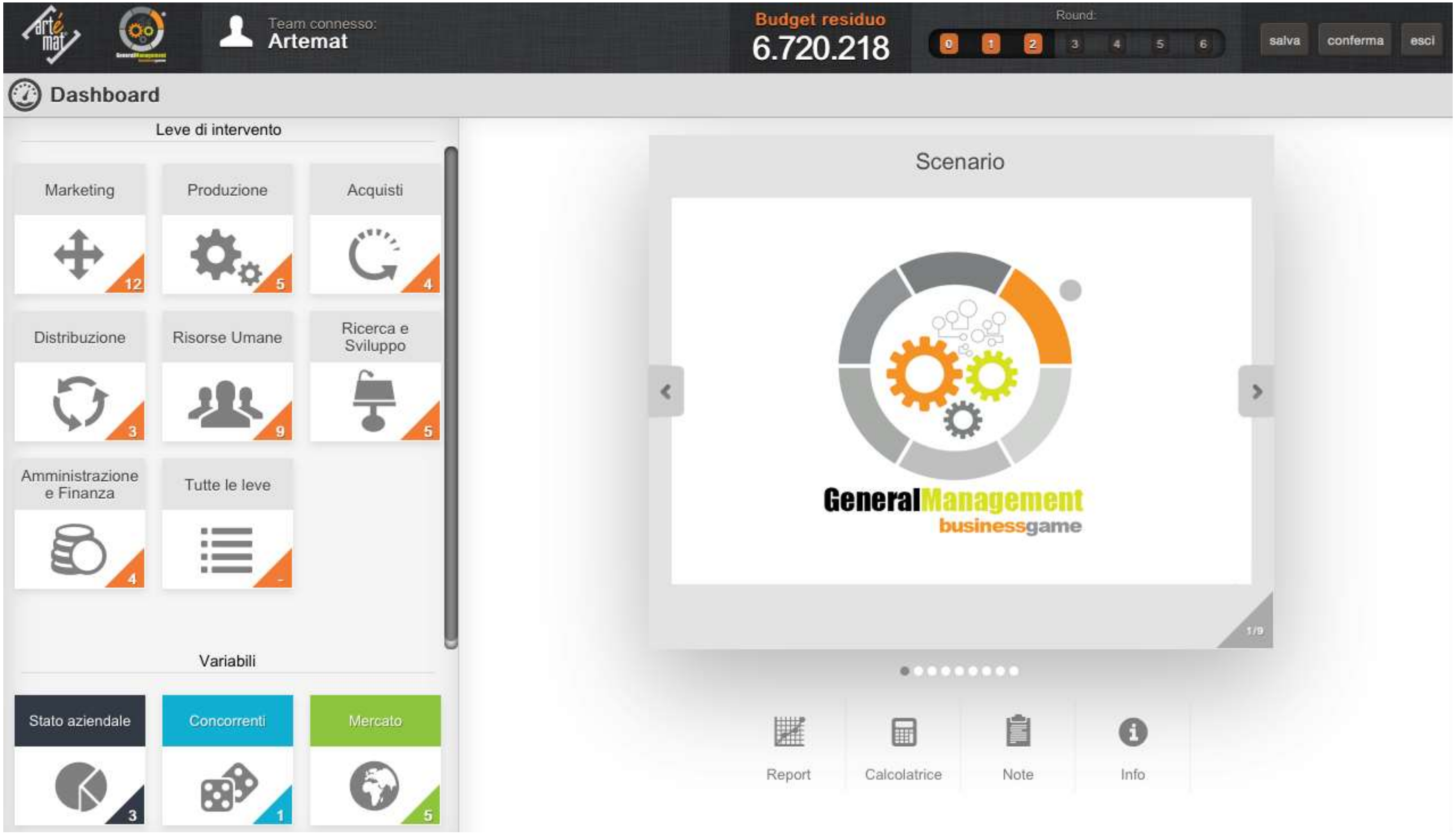
Applicativo web (autogenerato) che supporta il business game sul modello scelto

businessgamestudio

Possibilità di introdurre aziende «virtuali» nell'evento, utili per:
- Aumentare il realismo della simulazione, creando particolari condizioni di mercato
- Aumentare la dimensione della simulazione, e rendere fruibile il sistema anche ad utenti singoli o classi di piccole dimensioni

Supporto all'evento formativo mediante «facilitatori»

Esempio Interfaccia



Catalogo dei Modelli

businessgame start-up

Made in Calabria businessgame

TouriSim businessgame

Hemasi businessgame

HumanResource businessgame

GeneralManagement businessgame

Food&Wine businessgame

Banking businessgame

GreenManagement businessgame

Store management businessgame

CulturalEvent businessgame

Energy businessgame

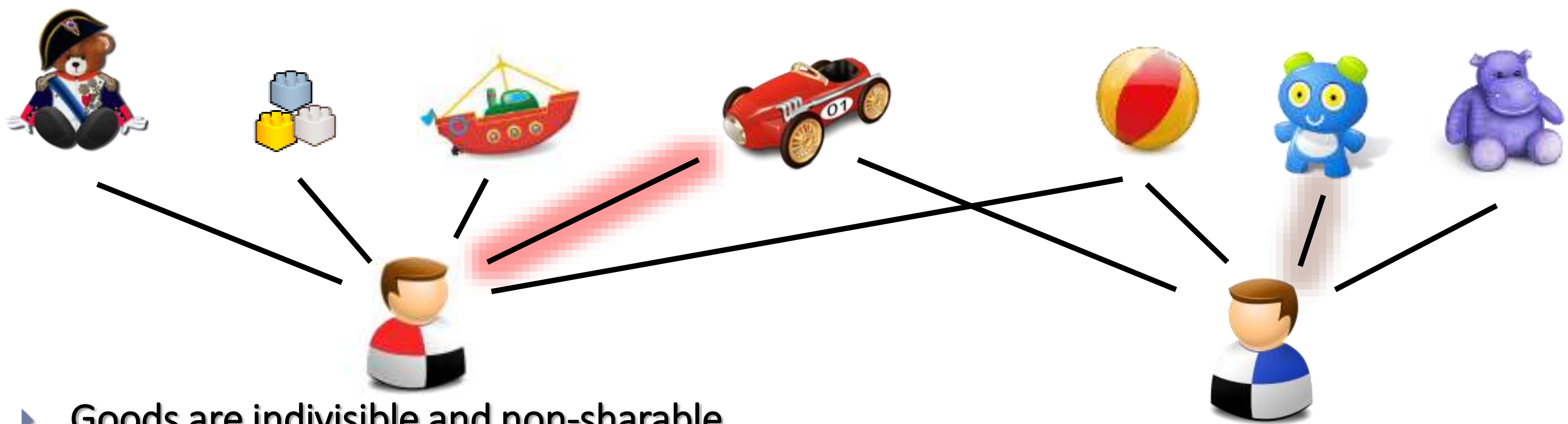
MarketingAcademy businessgame

MADE IN ITALY businessgame

SportManagement businessgame

COALITIONAL GAMES

The Model

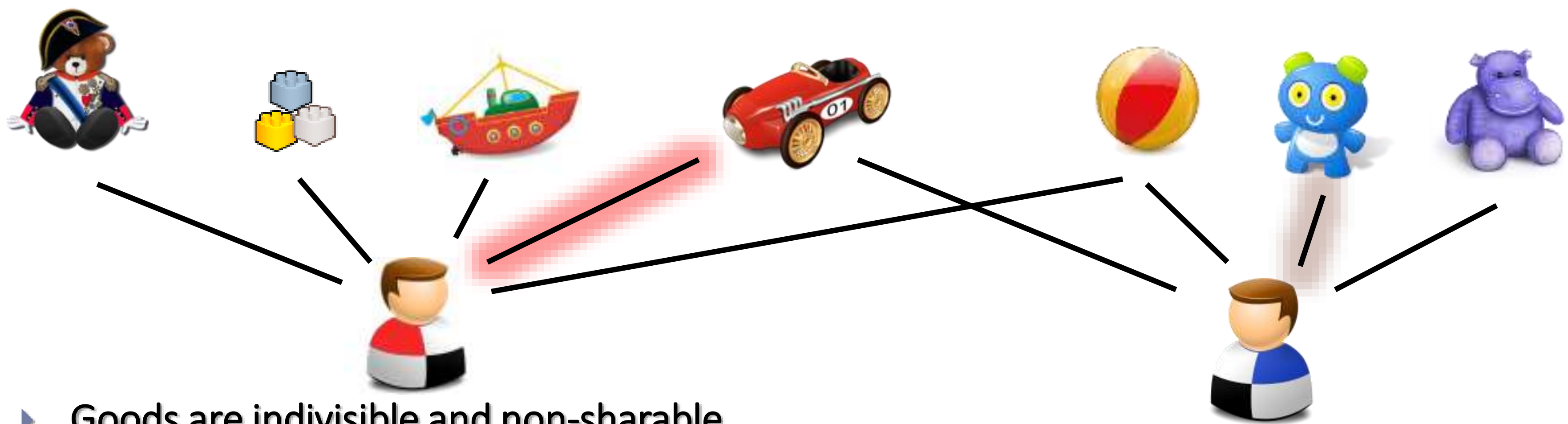


- Goods are indivisible and non-sharable
- Constraints on the max/min number of goods to be allocated to each agent
- Agent preferences: *Private* types VS *Declared* types

- Monetary compensation to induce truthfulness

see, e.g., [Shoham, Leyton-Brown; 2009]

The Model



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  «budget balance»

  - The algebraic sum of the monetary transfers is zero
  - In particular, mechanisms cannot run into deficit

Goals of the Allocation

- «Efficiency»
  - Maximize the social welfare
- «Fairness»
  - For instance, it is desirable that ***no agent envies*** the allocation of any another agent, or that
  - the selected outcome is ***Pareto efficient***, i.e., there must be no different allocation such that every agent gets at least the same utility and one of them even improves.

see, e.g., [Brandt, Endriss; 2012]

Impossibility Results

- Efficiency + Truthfulness + Budget Balance

  [Green, Laffont; 1977]
  [Hurwicz; 1975]

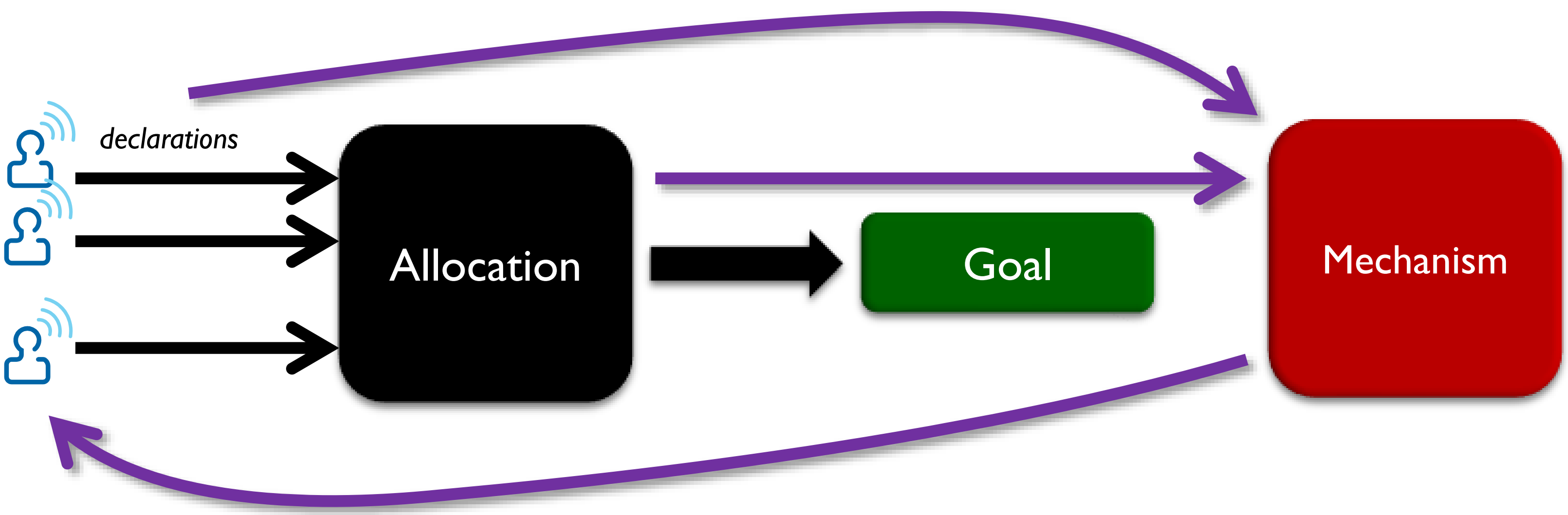
- Fairness + Truthfulness + Budget Balance

  [Tadenuma, Thomson; 1995]
  [Alcalde, Barberà; 1994]
  [Andersson, Svensson, Ehlers; 2010]

Impossibility Results

Efficiency + Truthfulness + Budget Balance

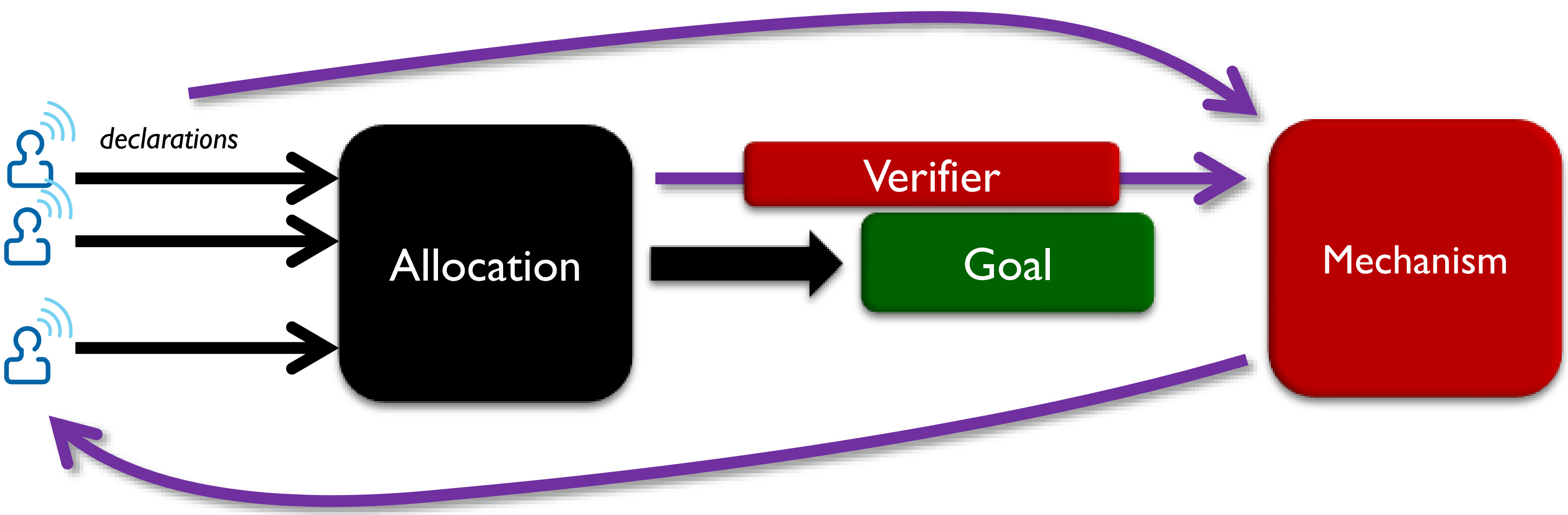
Fairness + Truthfulness + Budget Balance



Impossibility Results

- Efficiency + Truthfulness + Budget Balance
- Fairness + Truthfulness + Budget Balance

- Verification on «selected» declarations



Approaches to Verification

(1) Partial Verification

[Green, Laffont; 1986]
[Nisan, Ronen; 2001]

(2) Probabilistic Verification

Punishments are used to enforce truthfulness

Approaches to Verification

(1) Partial Verification

[Auletta, De Prisco, Ferrante, Krysta, Parlato, Penna, Persiano, Sorrentino, Ventre]

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Approaches to Verification

(1) Partial Verification

[Auletta, De Prisco, Ferrante, Krysta, Parlato, Penna, Persiano, Sorrentino, Ventre]

(2) Probabilistic Verification

[Caragiannis, Elkind, Szegedy, Yu; 2012]

Punishments are used to enforce truthfulness

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Approaches to Verification

(1) Partial Verification

(2) Probabilistic Verification

Punishments are used to enforce truthfulness

(3) Full Verification

No punishments!

VQR 2004-2010

- VQR 2004-2010: ANVUR should evaluate the quality of research of all Italian research structures
- Funds for the structures in the next years depend on the outcome of this evaluation
- Substructures will be also evaluated (e.g. university departments)

ANVUR Evaluation

ANVUR Criteria

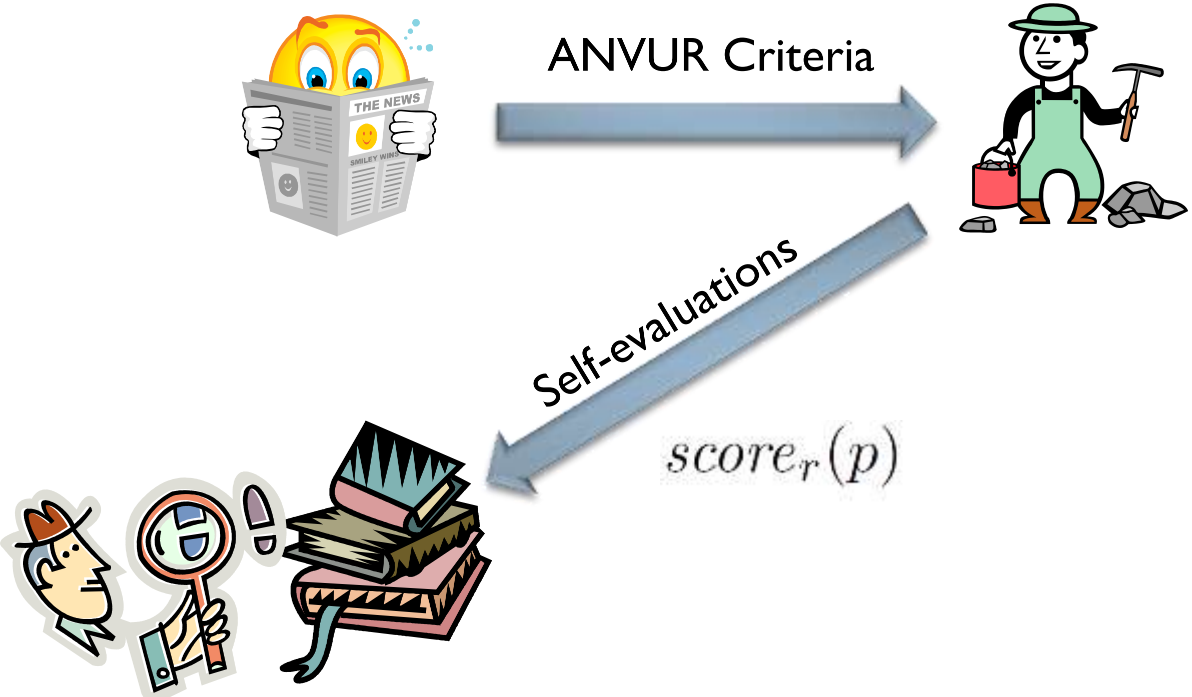
ANVUR Evaluation

ANVUR Criteria

Self-evaluations

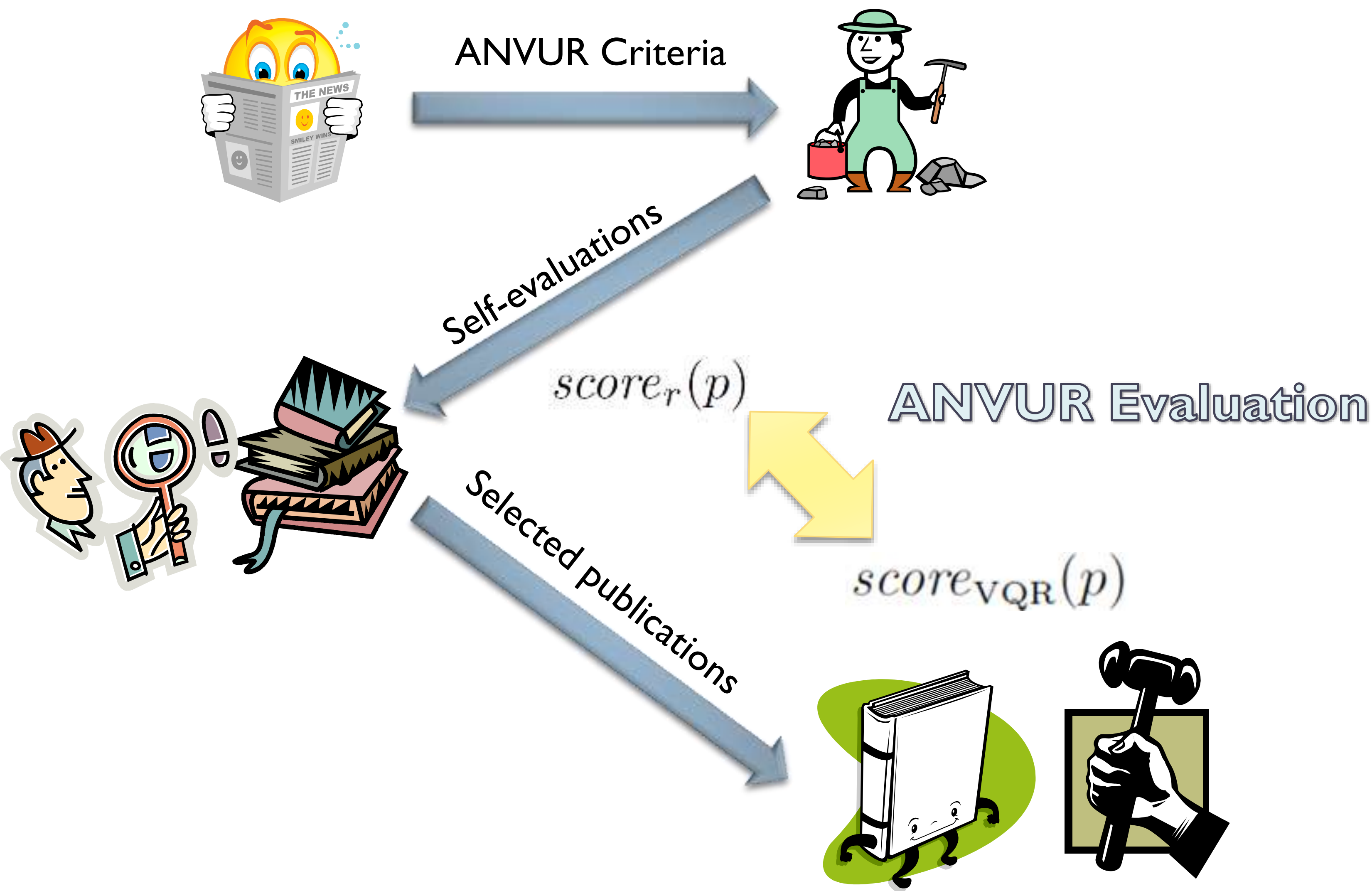
$score_r(p)$, for each $\begin{cases} r \in \mathcal{R} \\ p \in products(r) \end{cases}$

ANVUR Evaluation

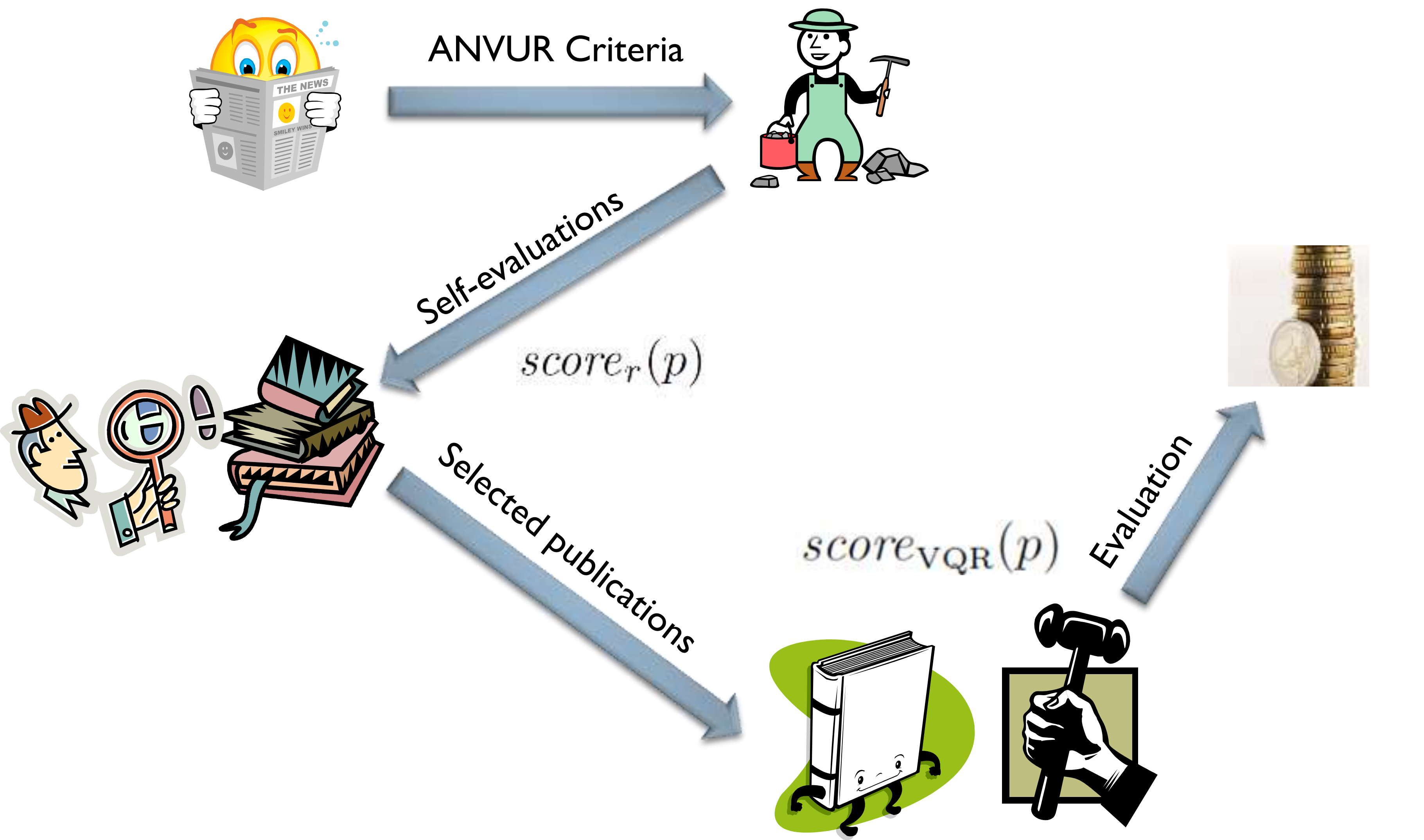


Structures are in charge of selecting the products to submit

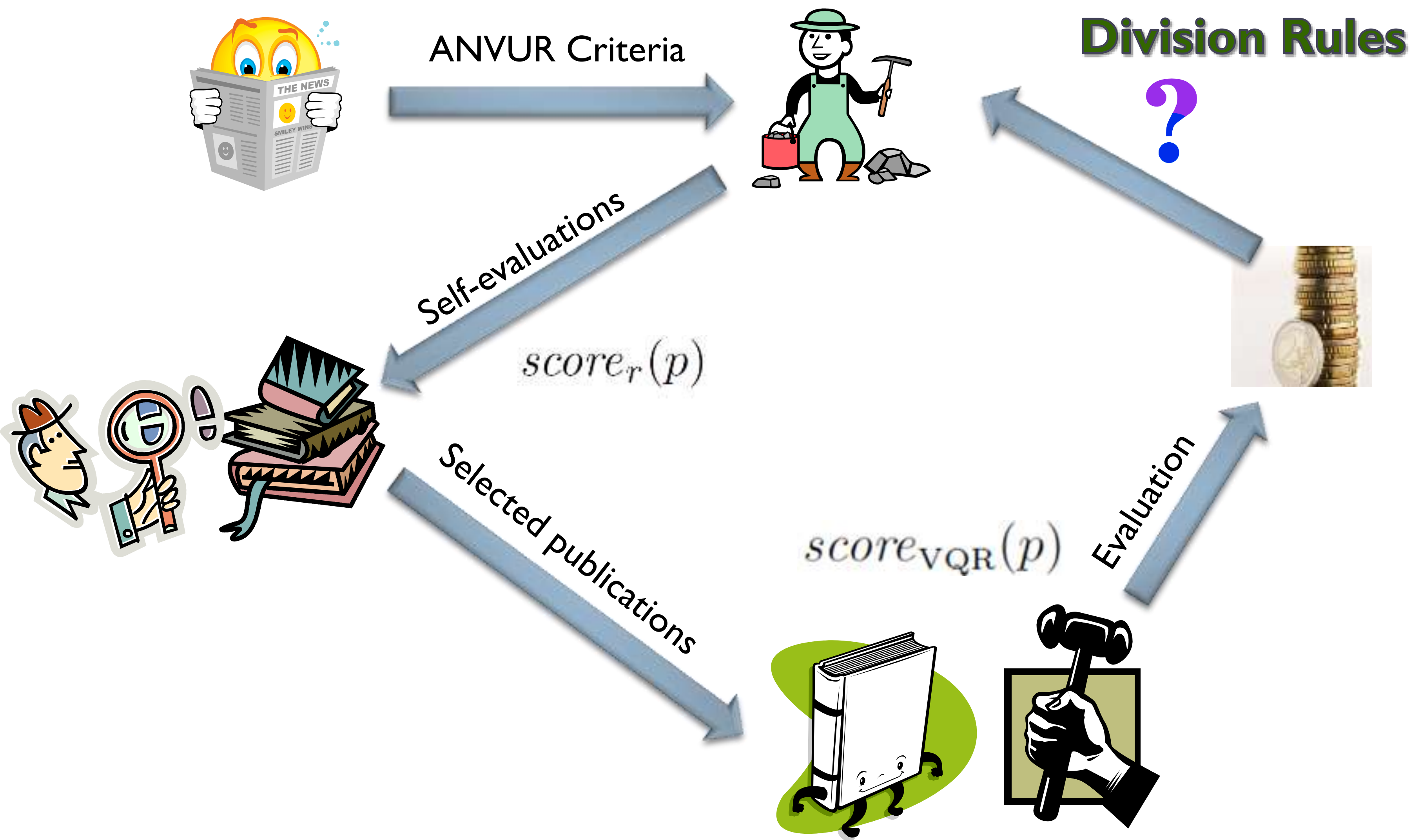
ANVUR Evaluation



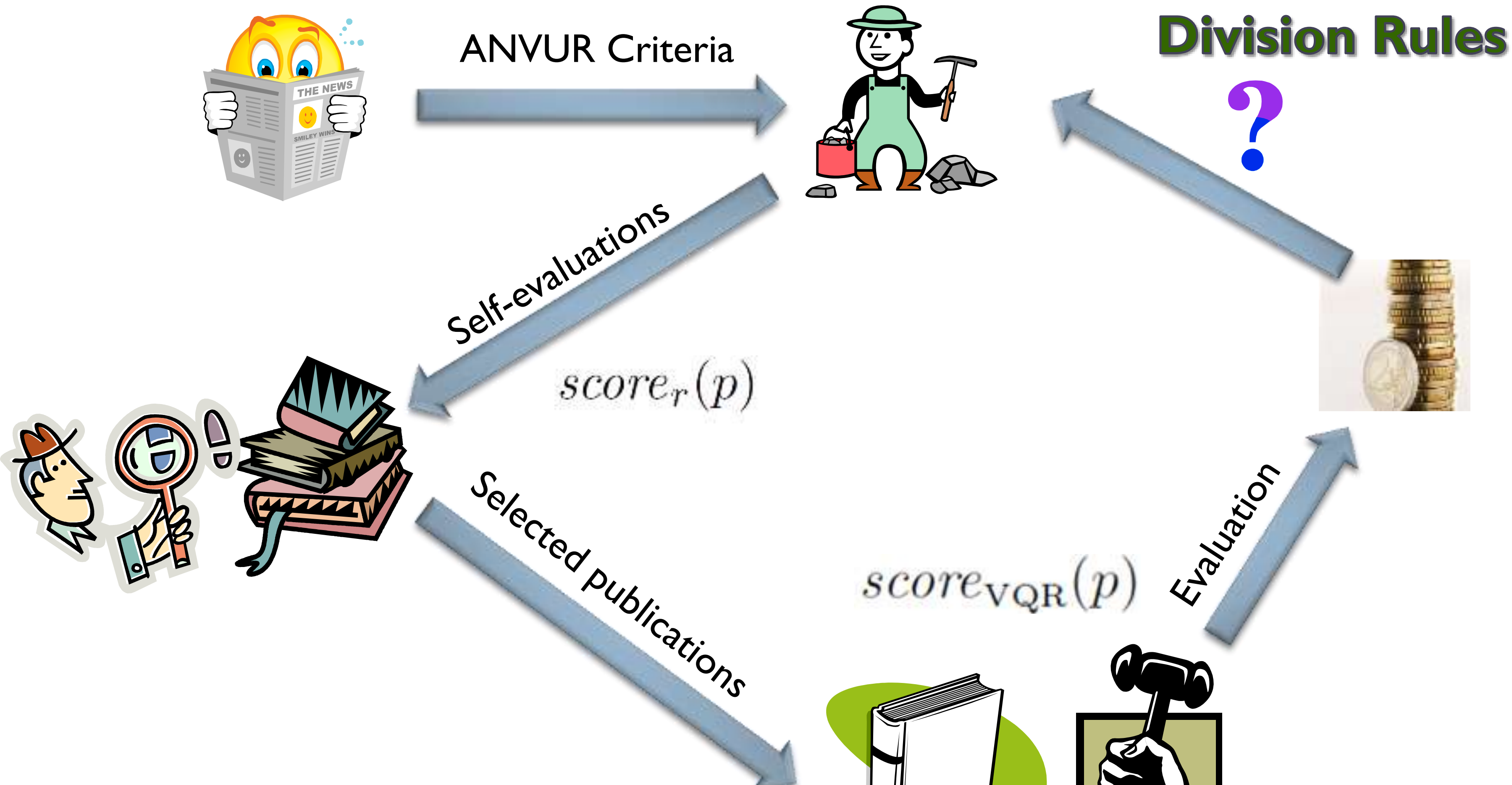
ANVUR Evaluation



ANVUR Evaluation



ANVUR Evaluation



$$\mathtt{proj}_r(\psi^*) = \sum_{p \in \psi*(r)} score_{VQR}(p)$$

The Mechanism [GS'14]

Input: An allocation π for $\langle \mathcal{A}, G, \omega \rangle$, and a vector $\mathbf{w} \in \mathbf{D}$;

Assumption: A verifier $\mathbf{v}$ is available. Let $\mathbf{v}(\pi) = (v_1, ..., v_n)$;

Let $\mathbb{C}$ denote the set of all possible subsets of $\mathcal{A}$;

For each set $\mathcal{C} \in \mathbb{C}$,

$\lfloor$ Compute an optimal allocation $\pi_{\mathcal{C}}$ for $\langle \mathcal{C}, \texttt{img}(\pi), \omega \rangle$ w.r.t. $\mathbf{w}$;

For each agent $i \in \mathcal{A}$,

| For each set $\mathcal{C} \in \mathbb{C}$,

| | Let $\Delta^1_{\mathcal{C},i}(\pi, \mathbf{w}) := \texttt{val}(\pi_{\mathcal{C}}, (v_i, \mathbf{w}_{-i}))$; $\quad (= v_i(\pi_{\mathcal{C}}) + \sum_{j \in \mathcal{C} \setminus \{i\}} w_j(\pi_{\mathcal{C}}))$;

| $\lfloor$ Let $\Delta^2_{\mathcal{C},i}(\pi, \mathbf{w}) := \texttt{val}(\pi_{\mathcal{C} \setminus \{i\}}, \mathbf{w})$; $\quad (= \sum_{j \in \mathcal{C} \setminus \{i\}} w_j(\pi_{\mathcal{C} \setminus \{i\}}))$;

| Let $\xi_i(\pi, \mathbf{w}) := \sum_{\mathcal{C} \in \mathbb{C}} \frac{(|\mathcal{A}| - |\mathcal{C}|)!(|\mathcal{C}|-1)!}{|\mathcal{A}|!} (\Delta^1_{\mathcal{C},i}(\pi, \mathbf{w}) - \Delta^2_{\mathcal{C},i}(\pi, \mathbf{w}))$;

$\lfloor$ Define $p^{\xi}_i(\pi, \mathbf{w}) := \xi_i(\pi, \mathbf{w}) - v_i(\pi)$;

[G., Scarcello JAIR'14]

The Mechanism [GS'14]

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1. Let $\mathbb{C}$ denote the set of all possible subsets of $\mathcal{A}$;
2. For each set $\mathcal{C} \in \mathbb{C}$,
3. Compute an optimal allocation $\pi_{\mathcal{C}}$ for $\langle \mathcal{C}, \texttt{img}(\pi), \omega \rangle$ w.r.t. $\mathbf{w}$;
4. For each agent $i \in \mathcal{A}$,
5. For each set $\mathcal{C} \in \mathbb{C}$,
6. Let $\Delta^1_{\mathcal{C},i}(\pi, \mathbf{w}) := \texttt{val}(\pi_{\mathcal{C}}, (v_i, \mathbf{w}_{-i}))$; $(= v_i(\pi_{\mathcal{C}}) + \sum_{j \in \mathcal{C} \setminus \{i\}} w_j(\pi_{\mathcal{C}}))$;
7. Let $\Delta^2_{\mathcal{C},i}(\pi, \mathbf{w}) := \texttt{val}(\pi_{\mathcal{C} \setminus \{i\}}, \mathbf{w})$; $(= \sum_{j \in \mathcal{C} \setminus \{i\}} w_j(\pi_{\mathcal{C} \setminus \{i\}}))$;
8. Let $\xi_i(\pi, \mathbf{w}) := \sum_{\mathcal{C} \in \mathbb{C}} \frac{(|\mathcal{A}| - |\mathcal{C}|)!(|\mathcal{C}| - 1)!}{|\mathcal{A}|!} (\Delta^1_{\mathcal{C},i}(\pi, \mathbf{w}) - \Delta^2_{\mathcal{C},i}(\pi, \mathbf{w}))$;
9. Define $p^{\xi}_i(\pi, \mathbf{w}) := \xi_i(\pi, \mathbf{w}) - v_i(\pi)$;

Allocated goods are considered only

The Mechanism [GS'14]

Input: An allocation π for $\langle \mathcal{A}, G, \omega \rangle$, and a vector $\mathbf{w} \in \mathbf{D}$;

Assumption: A verifier $\mathbf{v}$ is available. Let $\mathbf{v}(\pi) = (v_1, ..., v_n)$;

Let $\mathbb{C}$ denote the set of all possible subsets of $\mathcal{A}$;

For each set $\mathcal{C} \in \mathbb{C}$,

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- For each set $\mathcal{C} \in \mathbb{C}$,
  - Let $\Delta^1_{\mathcal{C},i}(\pi, \mathbf{w}) := \texttt{val}(\pi_{\mathcal{C}}, (v_i, \mathbf{w}_{-i}))$; $\quad (= v_i(\pi_{\mathcal{C}}) + \sum_{j \in \mathcal{C} \setminus \{i\}} w_j(\pi_{\mathcal{C}}))$;
  - Let $\Delta^2_{\mathcal{C},i}(\pi, \mathbf{w}) := \texttt{val}(\pi_{\mathcal{C} \setminus \{i\}}, \mathbf{w})$; $\quad (= \sum_{j \in \mathcal{C} \setminus \{i\}} w_j(\pi_{\mathcal{C} \setminus \{i\}}))$;
- Let $\xi_i(\pi, \mathbf{w}) := \sum_{\mathcal{C} \in \mathbb{C}} \frac{(|\mathcal{A}| - |\mathcal{C}|)!(|\mathcal{C}| - 1)!}{|\mathcal{A}|!} (\Delta^1_{\mathcal{C},i}(\pi, \mathbf{w}) - \Delta^2_{\mathcal{C},i}(\pi, \mathbf{w}))$;
- Define $p^{\xi}_i(\pi, \mathbf{w}) := \xi_i(\pi, \mathbf{w}) - v_i(\pi)$;

Allocated goods are considered only

In fact, allocated goods are the only ones that we verify

The Mechanism [GS'19]

Input: An allocation π for $\langle \mathcal{A}, G, \omega \rangle$, and a vector $\mathbf{w} \in \mathbf{D}$;
Assumption: A verifier $\mathbf{v}$ is available. Let $\mathbf{v}(\pi) = (v_1, ..., v_n)$;

1. Let $\mathbb{C}$ denote the set of all possible subsets of $\mathcal{A}$;
2. For each set $\mathcal{C} \in \mathbb{C}$,
3. Compute an optimal allocation $\pi_{\mathcal{C}}$ for $\langle \mathcal{C}, \mathtt{img}(\pi), \omega \rangle$ w.r.t. $\mathbf{w}$;
4. For each agent $i \in \mathcal{A}$,
5. For each set $\mathcal{C} \in \mathbb{C}$,
6. Let $\Delta^1_{\mathcal{C},i}(\pi, \mathbf{w}) := \mathtt{val}(\pi_{\mathcal{C}}, (v_i, \mathbf{w}_{-i}))$; $\quad (= v_i(\pi_{\mathcal{C}}) + \sum_{j \in \mathcal{C} \setminus \{i\}} w_j(\pi_{\mathcal{C}}))$;
7. Let $\Delta^2_{\mathcal{C},i}(\pi, \mathbf{w}) := \mathtt{val}(\pi_{\mathcal{C} \setminus \{i\}}, \mathbf{w})$; $\quad (= \sum_{j \in \mathcal{C} \setminus \{i\}} w_j(\pi_{\mathcal{C} \setminus \{i\}}))$;
8. Let $\xi_i(\pi, \mathbf{w}) := \sum_{\mathcal{C} \in \mathbb{C}} \frac{(|\mathcal{A}| - |\mathcal{C}|)!(|\mathcal{C}| - 1)!}{|\mathcal{A}|!} (\Delta^1_{\mathcal{C},i}(\pi, \mathbf{w}) - \Delta^2_{\mathcal{C},i}(\pi, \mathbf{w}))$;
9. Define $p^{\xi}_i(\pi, \mathbf{w}) := \xi_i(\pi, \mathbf{w}) - v_i(\pi)$;

Allocated goods are considered only

«Bonus and Compensation»,
by Nisan and Ronen (2001)

The Mechanism [GS'14]

Input: An allocation π for $\langle \mathcal{A}, G, \omega \rangle$, and a vector $\mathbf{w} \in \mathbf{D}$;

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Let $\mathbb{C}$ denote the set of all possible subsets of $\mathcal{A}$;

For each set $\mathcal{C} \in \mathbb{C}$,

⌊ Compute an optimal allocation $\pi_{\mathcal{C}}$ for $\langle \mathcal{C}, \mathtt{img}(\pi), \omega \rangle$ w.r.t. $\mathbf{w}$;

For each agent $i \in \mathcal{A}$,

| For each set $\mathcal{C} \in \mathbb{C}$,

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⌊ Define $p^{\xi}_i(\pi, \mathbf{w}) := \xi_i(\pi, \mathbf{w}) - v_i(\pi)$;

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No punishments!

The Mechanism [GS'14]

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9. Define $p^\xi_i(\pi, \mathbf{w}) := \xi_i(\pi, \mathbf{w}) - v_i(\pi)$;

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«Bonus and Compensation», by Nisan and Ronen (2001)

❖ **Truth-telling is a dominant strategy for each agent**

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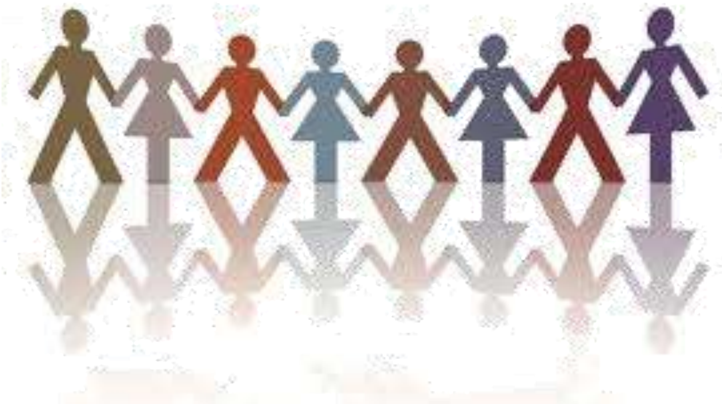
❖ **Truth-telling is a dominant strategy for each agent**

Coalitional Games

- Players form *coalitions*
- Each coalition is associated with a *worth*
- A *total worth* has to be distributed

$$\mathcal{G} = \langle N, \varphi \rangle,\ \varphi : 2^N \mapsto \mathbb{R}$$



- **Solution Concepts** characterize outcomes in terms of
  - Fairness
  - Stability

Shapley Value

$$\phi_i(\mathcal{G}) = \sum_{C \subseteq N} \frac{(|N| - |C|)!(|C| - 1)!}{|N|!}(\varphi(C) - \varphi(C \setminus \{i\}))$$

- **Solution Concepts** characterize outcomes in terms of
  - Fairness
  - Stability

The Mechanism [GS'14]

$$\mathcal{G} = \langle N, \varphi \rangle,\ \varphi\colon 2^N \mapsto \mathbb{R}$$

$\varphi(C)$ is the *contribution* of the coalition **w.r.t.**

selected products

and

verified values

The Mechanism [GS'14]

$$\mathcal{G} = \langle N, \varphi \rangle,\ \varphi: 2^N \mapsto \mathbb{R}$$

$\varphi(C)$ is the *contribution* of the coalition **w.r.t.** { **selected products** *and* **verified values** }

Best possible allocation,
assuming that agents in C are the only ones in the game

The Mechanism [GS'14]

$\mathcal{G} = \langle N, \varphi \rangle, \; \varphi : 2^N \mapsto \mathbb{R}$

$\varphi(C)$ is the *contribution* of the coalition **w.r.t.** { **selected products** *and* **verified values** }

→ Each researcher gets the Shapley value $\phi_i(\mathcal{G})$

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Properties

- The resulting mechanism is «efficient», «fair» and «buget balanced»
- Essentially, it is the **only** possible mechanism enjoying these properties!

GRAZIE