FAIR SHARING OF EARTH OBSERVING SATELLITE RESOURCES $\longrightarrow$ PLEIADES system

M. Lemaître
formerly ONERA Toulouse, France

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context

Studies : *sharing the use of the PLEIADES system*

driven by

Office National d'Études et de Recherches Aérospatiales (ONERA)

for

Centre National d'Etudes Spatiales (CNES)

from 2001 to 2004.

- M. Lemaître, M. Llibre, G. Verfaillie, ONERA
- N. Bataille, J.-M. Lachiver, CNES
- H. Fargier, J. Lang, CNRS / IRIT

plan of the talk

1. PLEIADES
2. basic sharing model
3. complications
4. feedback and impact

PLEIADES : a system of Earth Observing Satellites

Optical observation system of 2 satellites

Colour images 50 cm, mono, stereo

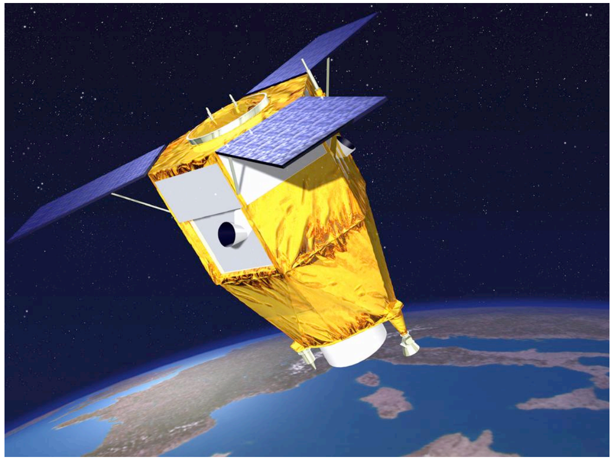
Daily visit on any point on the globe

Dual usage : defense and civilian

Launched in 2011 and 2012, operational since 2013

Co-funded by several space agencies (France / Italy / Spain)

Developed by CNES,
build and operated by Airbus Defense and Space (ex Astrium)



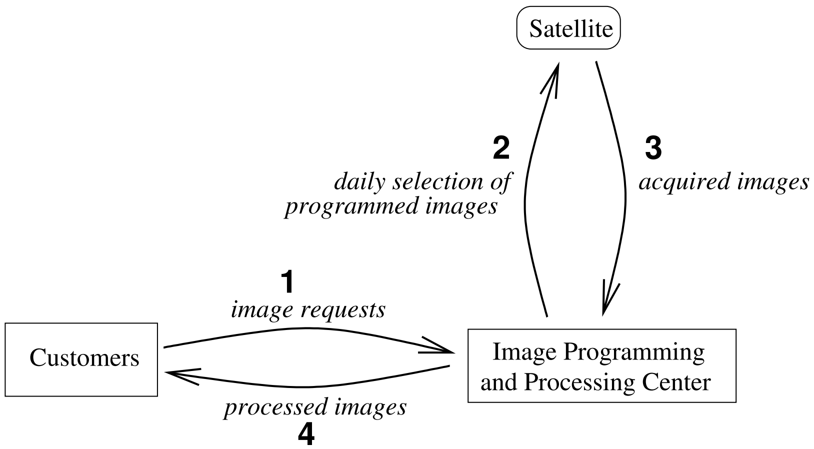
Figures/prise_de_vue.mpeg

http://videos-en.astrium.eads.net/#/video/iLyROoafzJzU

http://www.geo-airbusds.com/pleiades/

PLEIADES system mission

To acquire *images*, in response to *requests* from *customers*.



PLEIADES fair sharing problem (informal) 1/2

Each 8 hours, build an *acquisition plan* for the next 8 hours

For each plan, *select* a subset of images to be programmed

Every day, hundreds of feasible images ...
All feasible images cannot be programmed in the same plan,
due to *conflicts* between them
(respect of physical constraints)

Each (plan) selection of programmed images is
an allocation of indivisible objects (images) to agents
subject to constraints

PLEIADES fair sharing problem (informal) 2/2

Each allocation must be

- *admissible* :
  respect constraints
- *efficient* :
  the system must not be under-exploited
- *fair* :
  system co-funded by several countries (*agents*)
  France/Italy/Spain
  and **exploited in common**

  The "returns on investment" should be, for the agents, proportional to their (unequal) financial contribution
  $\longrightarrow$ *entitlements*

our work

1. understand, clarify needs and wishes
2. formalise
3. design methods/algorithms

We advocated a clear separation between
model (utilities, efficiency, fairness, ...) and resolution (algorithms)

Centralized resolution procedure

fair allocation problem : basic model (1/2)

agents and objects

- $N = \{1, \cdots, n\}$: *agents*
- $\mathcal{O}$: *indivisible objects* (images)
- $\Delta_1, \cdots, \Delta_n$, with $\Delta_i \subseteq \mathcal{O}$: *demands* of agents (requested images)
  $\Delta_i \cap \Delta_j = \emptyset$ for all $i \neq j$
  $\Delta \stackrel{\text{def}}{=} \cup_i \Delta_i$
- $\mathbf{x} = \langle x_1, \cdots, x_n \rangle$: an *allocation*
  where $x_i \subseteq \Delta_i$ is the *share* of agent i in $\mathbf{x}$
- $Adm(\Delta)$: set of *admissible allocations* for Δ

fair allocation problem : basic model (2/2)

preferences and utilities

- $w(o) \in \mathbb{R}^{+*}$: *weight* given to object o (by the agent requesting it)
  $\longrightarrow$ weights are set freely by agents
- $u(x_i, \Delta_i) \in \mathbb{R}^{+}$: *individual utility* of x for i, measure of individual satisfaction
- $uc(\mathsf{x}, \Delta) \in \mathbb{R}^{+}$: *collective utility* of x, measure of collective satisfaction

Each agent i wants its individual utility $u(x_i, \Delta_i)$ maximized.

"Best" allocation : maximize the collective utility $uc(\mathbf{x}, \Delta)$.

$\rightarrow$ *How to define $u(x_i, \Delta_i)$ and $uc(\mathbf{x}, \Delta)$?*

Agents' *entitlements* : $\mathbf{e} = \langle e_1, \cdots, e_n \rangle$

ex : 25, 11, 3

individual utilities

A simple approach :
additive utilities

→ first try :

$$u(x_i, \Delta_i) \stackrel{\text{def}}{=} \sum_{o \in x_i} w(o)$$

agents are indifferent to get 2 objects of weights (w_1, w_2)
or 1 object of weight $(w_1 + w_2)$

normalisation of individual utilities

We need to express individual utilities on a *common scale*

$\longrightarrow$ *normalised individual utility* (Kalai-Smorodinsky) :

$$u(x_i, \Delta_i) \stackrel{\text{def}}{=} \frac{\sum_{o \in x_i} w(o)}{\max_{x \in Adm(\Delta_i)} \sum_{o \in x} w(o)}$$

$$u(x_i, \Delta_i) \in [0, 1]$$

collective utility

$$uc(\mathbf{x}, \Delta) = g(\langle u(x_1, \Delta_1), \cdots, u(x_n, \Delta_n)\rangle, \mathbf{e})$$

Desirable properties :

- monotonicity : $uc(\mathbf{x}, \Delta)$ should increase when $u(x_i, \Delta_i)$ increases
  $\rightarrow$ Pareto-efficiency
- fairness
  $\rightarrow$ at least symetry (anonymicity)
  $\rightarrow$? «fair share», «inequality reduction (Pigou-Dalton)», ... ?

Many possibilities ...

collective utility function

«Ethical» choices

- egalitarianism
- classical utilitarianism
- compromises, Nash

egalitarianism

with equal entitlements : $uc(\mathbf{x}, \Delta) \stackrel{\text{def}}{=} \min_i u(x_i, \Delta_i)$

with unequal entitlements : $uc(\mathbf{x}, \Delta) \stackrel{\text{def}}{=} \min_i \dfrac{u(x_i, \Delta_i)}{e_i}$

$\longrightarrow$ tend to maximize the $u(x_i, \Delta_i)$
and make them *proportional* to e_i

Needs a small improvement to get monotonicity :
the leximin *social welfare preordering*.

$$a = (2, 9, 2) \qquad \longrightarrow (2, 2, 9)$$
$$b = (3, 2, 3) \qquad \longrightarrow (2, 3, 3)$$
$$b >_{\text{leximin}} a$$

classical utilitarianism

with equal entitlements : $uc(\mathbf{x}, \Delta) = \sum_i u(x_i, \Delta_i)$

with unequal entitlements : ?

$$uc(\mathbf{x}, \Delta) = \sum_i e_i \cdot u(x_i, \Delta_i)$$

(questionable)

$\longrightarrow$ *in this approach, equity is not a strong concern*
but it can work either ...

Is it fair ? we are indifferent between
giving δu_i to i or giving δu_j to j, if $q_i \cdot \delta u_i = q_j \cdot \delta u_j$,
not considering whether i is already richer or poorer than j.

compromises : OWA

Ordered Weighted Averaging (OWA) operators [Yager 88]

$$u(\mathsf{x}) \stackrel{\text{def}}{=} \langle u_1, u_2, \ldots, u_n \rangle$$

$$u^\star(\mathsf{x}) \stackrel{\text{def}}{=} \langle u_1^\star, u_2^\star, \ldots, u_n^\star \rangle$$

the same as $u(\mathsf{x})$ but sorted increasing. Then

$$uc(\mathsf{x}) \stackrel{\text{def}}{=} \sum_i \alpha^{i-1} \cdot u_i^\star, \ \textit{with } \alpha \in]0, 1].$$

- $\alpha = 1 \rightarrow$ pure utilitarianism
- α small enough $\rightarrow$ egalitarianism (leximin preordering).

compromises : SE

«Sum of Exponents» operators [Moulin 1988 / 2003]
Additive family.

$$uc_{(p)}(\mathsf{x}) \stackrel{\text{def}}{=} \sum_i g_{(p)}(u_i), \quad p \leq 1$$

$$\text{with } g_{(p)}(u) \stackrel{\text{def}}{=} \mathrm{sgn}(p) \cdot u^p \ , \ p \neq 0$$

$\mathrm{sgn}(p) \stackrel{\text{def}}{=} 1$ if $p > 0$, $\mathrm{sgn}(p) \stackrel{\text{def}}{=} -1$ if $p < 0$

$$g_{(0)}(u) \stackrel{\text{def}}{=} \log u \quad (\textit{Nash})$$

- $p = 1$: pure utilitarianism
- $p \to -\infty$: egalitarianism (leximin preordering).

insights into the real problem

- each plan is built from 3 sequential "phases"
  1 - defense : constrained number of images (ex : 25, 11, 5)
  2 - civilian : idem (ex : 100, 44, 20)
  3 - "routine" : entitlements
- repeated planification
- *big* and *difficult* optimisation problem in constrained time

other studied topics

- Elicitation of preferences (weights)
- Manipulations
- Temporal regulation
- Common requests
- Planning, heuristics

feedback

Many of our propositions (not all) have been implemented into the operational ground system.

Accepted propositions :

- separation model / resolution
- utility based model
- normalisation
- cooperative aspects : common requests
- preference elicitation

feedback (continued)

Rejected propositions :

- egalitarian sharing (min criteria)
  was considered too favourable towards less entitled agents
  $\longrightarrow$ a weighted sum was actually chosen.

Refitted propositions :

- in the first sharing phase (defense)
  a negotiation step was added :
  - to define common requests (if any)
  - a reference ("optimal") allocation is computed,
  plus several "good" allocations,
  on which they negotiate / vote.

impact

Research contributions on fair division of indivisible goods
(Sylvain Bouveret' thesis, articles)

- leximin optimisation
- unequal fair division (entitlements)
- complexity
- compact preference representation
- fair division of indivisible goods under risk (Charles Lumet's thesis)
- logical fairness criteria

https://sites.google.com/site/michellemaitre31/
http://recherche.noiraudes.net

message

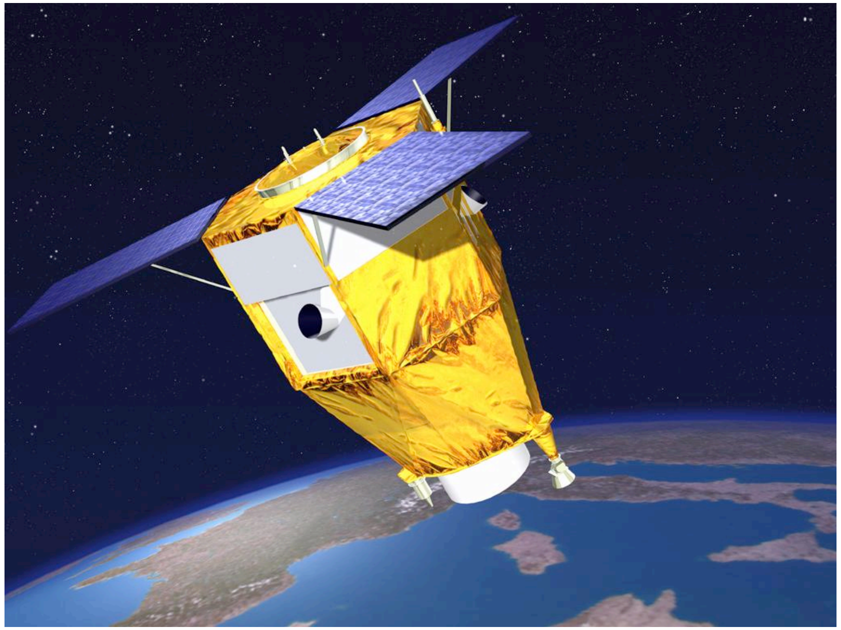
Fair division problems do exist in the real world !

They are not simple and certainly not "pure" fairness problems

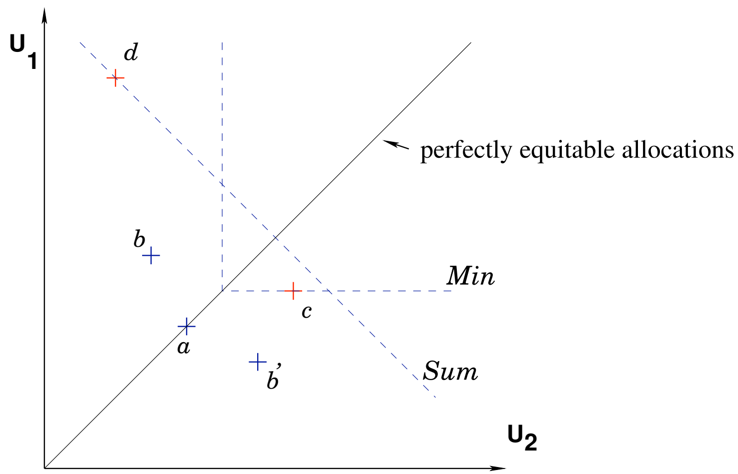
We (scientists) need good listening and pedagogical skills
to make your propositions considered and accepted

H. Moulin, Axioms of Cooperative Decision Making, 1988

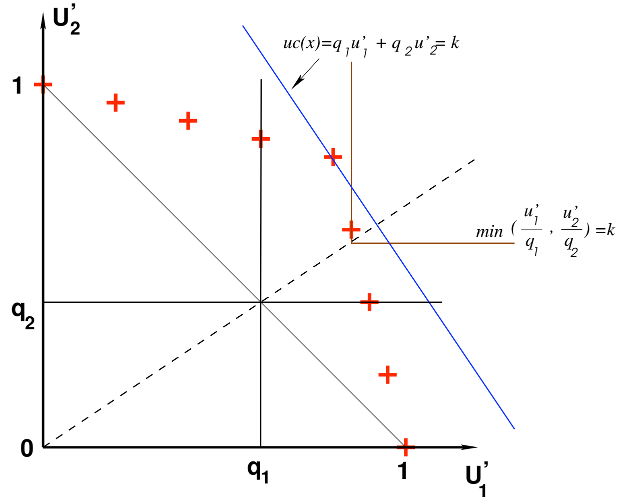
H. Moulin, Fair Division and Collective Welfare, 2003

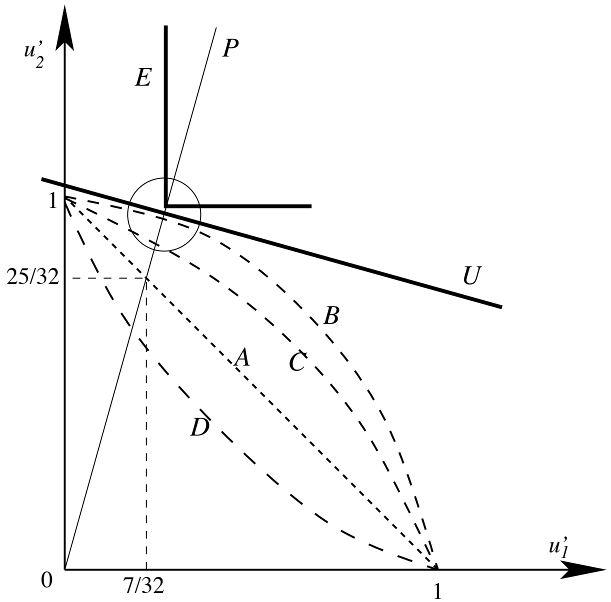


egalitarian and classical utilitarian with equal entitlements



classical utilitarianism, egalitarianism and fairness with unequal entitlements





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