

FAIR SHARING OF  
EARTH OBSERVING SATELLITE RESOURCES  
→ PLEIADES system

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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'Études 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

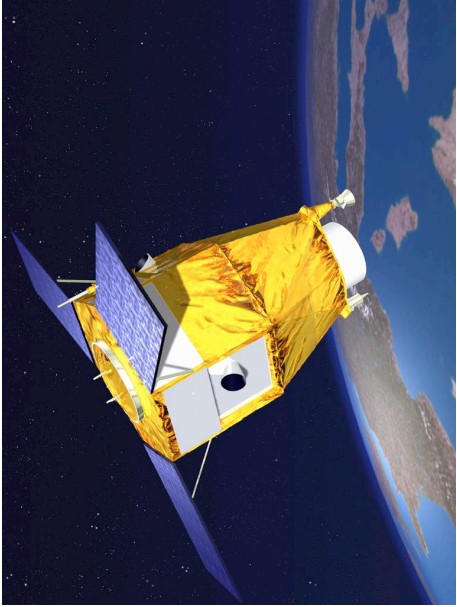
Daily visit on any point on the globe

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,  
built and operated by Airbus Defense and Space (ex Astrium)



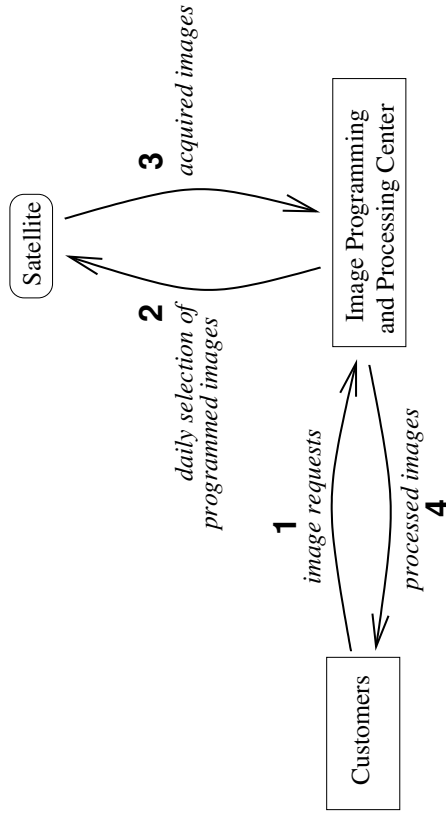
Figures/prise\_de\_vue.mpeg

<http://videos-en.astrium.eads.net/#/video/iLyR0oafzJzU>

<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  
→ *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

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

## 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)  
→ *weights are set freely by agents*
- ▶  $u(x_i, \Delta_i) \in \mathbb{R}^+$  : *individual utility* of  $x$  for  $i$ ,  
measure of individual satisfaction
- ▶  $uc(x, \Delta) \in \mathbb{R}^+$  : *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  $uc(x, \Delta)$ .

→ *How to define  $u(x_i, \Delta_i)$  and  $uc(x, \Delta)$  ?*

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

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*

→ *normalised individual utility* (Kalai-Smorodinsky) :

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

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



## collective utility

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

Desirable properties :

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

Many possibilities ...

collective utility function

- ▶ «Ethical» choices
- ▶ egalitarianism
- ▶ classical utilitarianism
- ▶ compromises, Nash

## egalitarianism

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

with unequal entitlements :  $uc(x, \Delta) \stackrel{\text{def}}{=} \min_i \frac{u(x_i, \Delta_i)}{e_i}$   
→ 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*.

$$\begin{array}{ll} a = (2, 9, 2) & \rightarrow (2, 2, 9) \\ b = (3, 2, 3) & \rightarrow (2, 3, 3) \end{array} \quad b \succ_{\text{leximin}} a$$

## 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)

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

Is it fair ? we are indifferent between giving  $\delta u_i$  to  $i$  or giving  $\delta u_j$  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]

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

$$u^*(\mathbf{x}) \stackrel{\text{def}}{=} \langle u_1^*, u_2^*, \dots, u_n^* \rangle$$

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

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

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

## compromises : SE

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

$$u_{C(p)}(\mathbf{x}) \stackrel{\text{def}}{=} \sum_i g_{(p)}(u_i), \quad p \leq 1$$

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

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

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

- ▶  $p = 1$  : pure utilitarianism
- ▶  $p \rightarrow -\infty$  : 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  
→ 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/michellemaître31/>  
<http://recherche.noiraudes.net>

message

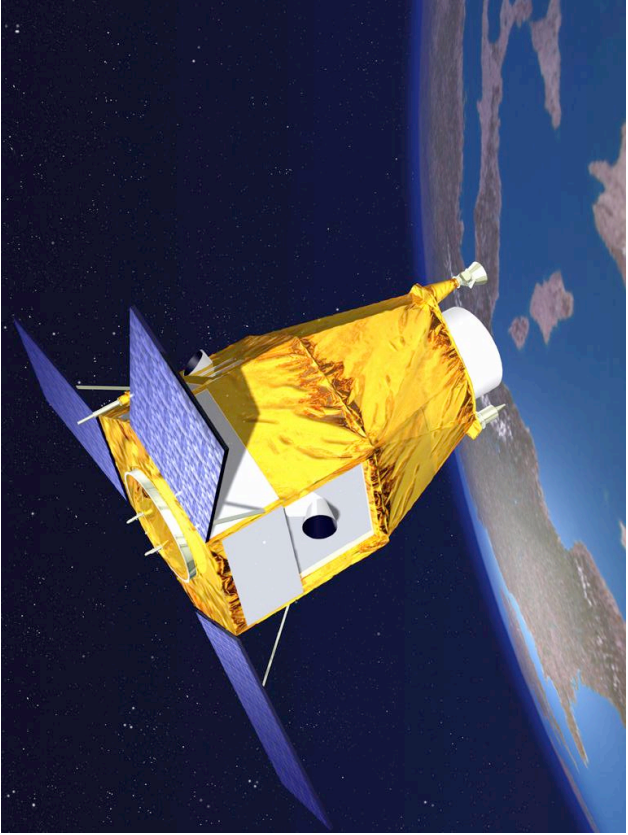
**Fair division problems do exist  
in the real world !**

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

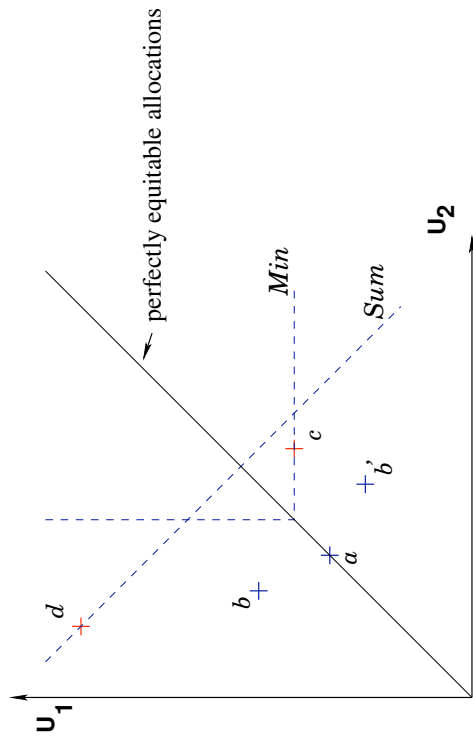
We (scientists) need good listening and pedagogical skills  
to make your propositions considered and accepted

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

