ELECTRONICS & DEFENSE

IA Distribuée pour des systèmes embarqués plus fiables et plus résilients

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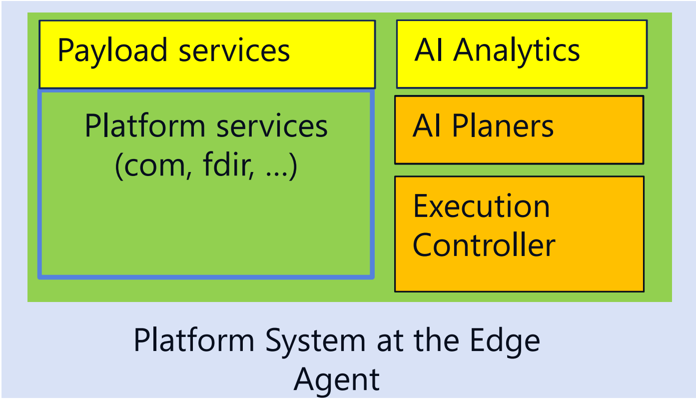
Introduction et contexte

- **Le domaine tactique:** nécessite la gestion d'une grande variété d'activités en temps réel, devant être optimisées.
- **Le calcul à l'edge :** permet des comportements plus autonomes en évitant de remonter systématiquement les données du champs de bataille. Tendance duale.
- **Nouveaux schémas de communication (MANET, Sat)** permettent la coordination de plusieurs entités de différents niveaux
- **Comportement collectif intelligents:** permet une utilisation responsable de l'IA



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Niveaux d’autonomie des systèmes – ALFUS, NIST

NIST: RETEX 2019 et extensions 2021 aux systèmes autonomes et collaboratifs

➔ **Mission / System**
- **Resource and states management**
- **Operational Efficiency**
- **Adaptability**

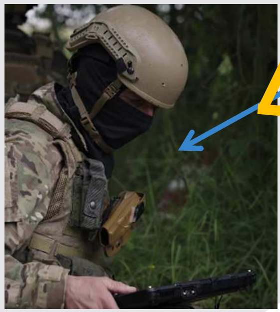
Process automation
Autonomous execution

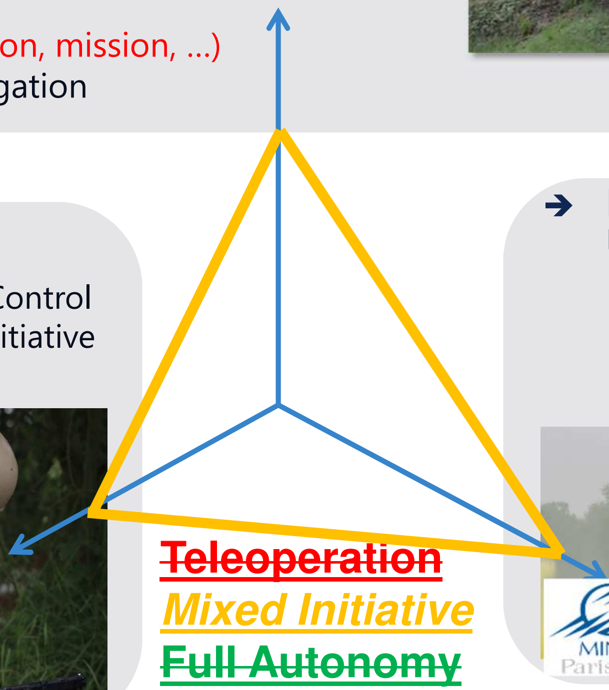
1. Simple task / process automation (control, perception,…), plan off line
2. Re-plan capability (navigation, mission, …)
3. Adaptability mission / navigation

➔ **Interactivity**
- **Platform Management**
- **Real Time Observations**
- **Nav/Mission Management**

Shared Control
Mixed initiative

1. Human in the loop (2/3-3/3)
2. Adujstable autonomy (1/3-2/3)
3. Human on the loop (<1/3)
4. Autonomy





➔ **Environment Dynamics / Uncertainty**
- **Terrain**
- **Obstacles**
- **Threats**

Knowledge

1. No constraint, very limited risk
2. Constraint (navigability, weather, …) with unknown, limited risk
3. Constraint, unknown and uncertain, risk
4. Adversarial, important risk

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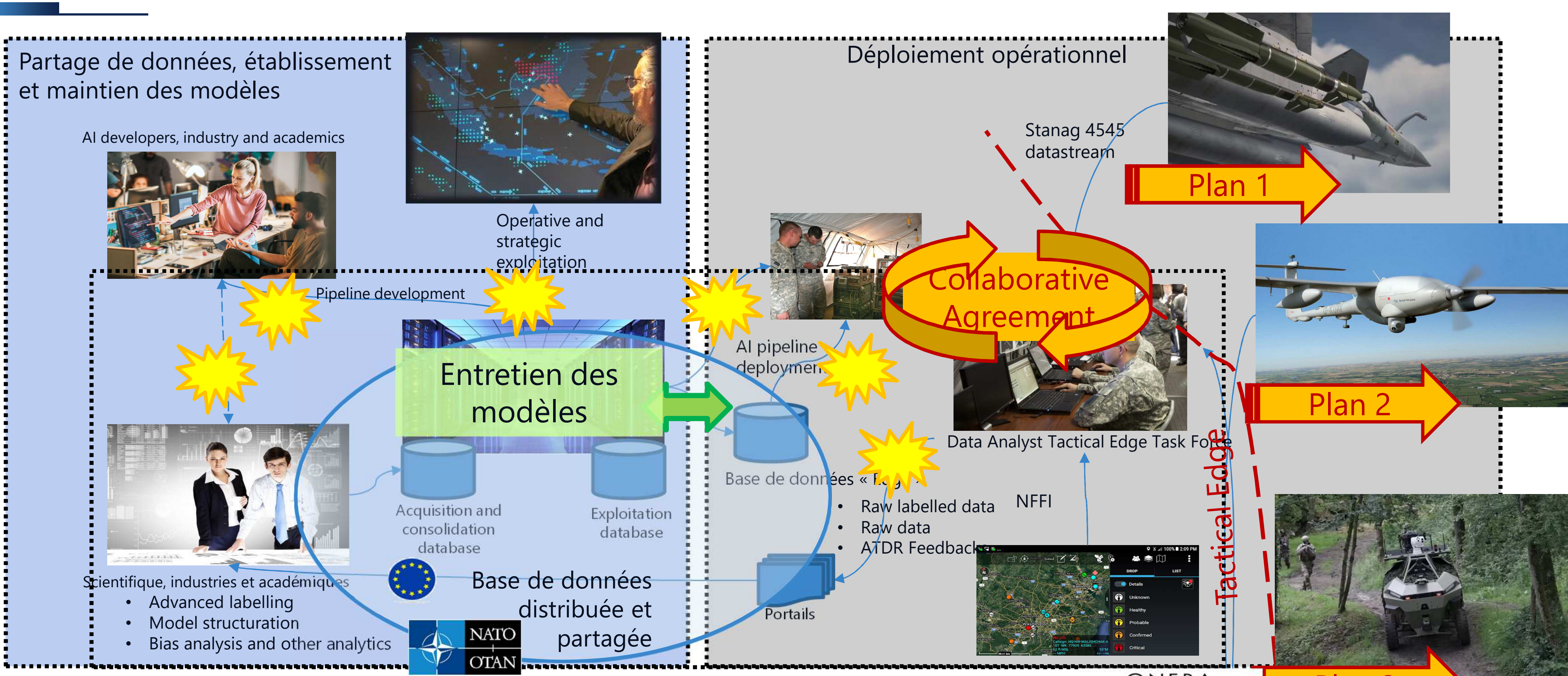
Planification et execution aeroterrestre pour le « tactical edge »



Projets: FURIOUS (DGA) , CUGS (AED), iMUGS (FED), PARHERO (AID), …

Guettier, C., Lamal, W., Mayk, I., & Yelloz, J and a. . (2015). Design and Experiment of a Collaborative Planning Service for NetCentric International Brigade Command. *Proceedings of the AAAI Conference on Artificial Intelligence*, *29*(2), 3967-3974.

Etat de l'art et optimisation distribuée

En théorie:
Profusion d'écoles en systèmes distribués / agents

- **Protocoles d'accord**
  - Election de leader, Global snapshot
  - Diffusion atomique, Consensus
- **Protocoles intelligent**
  - Inférence logique distribuée
  - Négociation, Argumentation, Enchères
- **Optimisation sous contraintes distribuées**
  - Asynchronous backtracking
  - Asynchronous weak commitment (AWC)

N. Nethercote, P. J. Stuckey, R. Becket, S. Brand, G. J. Duck, and G. Tack, "Minizinc: Towards a standard cp modelling language," in *International Conference on Principles and Practice of Constraint Programming*. Springer, 2007, pp. 529–543.

M. Yokoo, "Asynchronous weak-commitment search for solving distributed constraint satisfaction problems," in *International Conference on Principles and Practice of Constraint Programming*. Springer, 1995, pp. 88–102.

En pratique:
Profusion d'approches dans le spatial et aéro

M. Lemaître, G. Verfaillie, F. Jouhaud, J.-M. Lachiver, and N. Bataille, "Selecting and scheduling observations of agile satellites," *Aerospace Science and Technology*, vol. 6, no. 5, pp. 367–381, 2002.

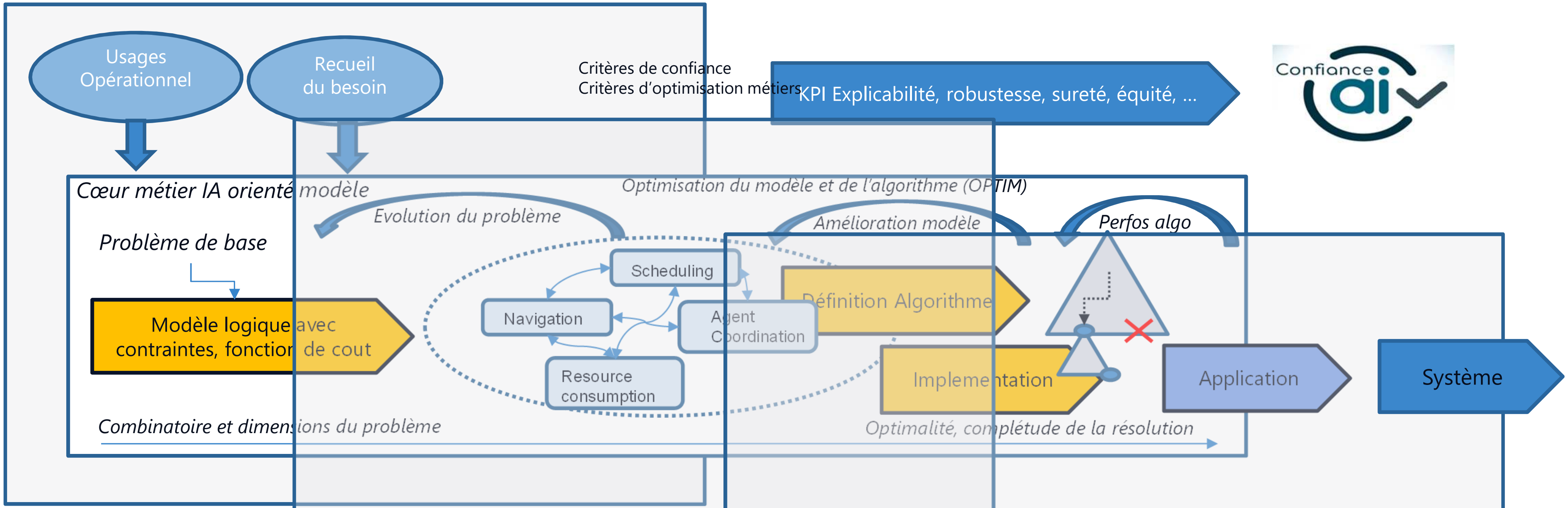
N. Cramer, D. Cellucci, C. Adams, A. Sweet, M. Hejase, J. Frank, R. Levinson, S. Gridnev, and L. Brown, "Design and testing of autonomous distributed space systems," in *35th Annual Small Satellite Conference*, no. SSC21-NST-04, 2021.

G. Picard, "Auction-based and distributed optimization approaches for scheduling observations in satellite constellations with exclusive orbit portions," *arXiv preprint arXiv:2106.03548*, 2022.

I. Zilberstein, A. Rao, M. Salis, and S. Chien, "Decentralized, decomposition-based observation scheduling for a large-scale satellite constellation," in *34th International Conference on Automated Planning and Scheduling*, 2024.

- **Résolution des problèmes en "local":**
  - solvers de contraintes: MiniZinc, with Shuffled, GeCode, COIN-BC, OR Tools …
  - planificateurs indépendants ou dédiés

Conception des modèles



- **Renforcement**
- **GNN et CP hybridée**
- **Apprentissage actif**
  - 1. Quelles variables?
  - 2. Décomposition de la fonction de cout!

- **Relaxation**
- **Résolution distribuée**
  - 1. Quelles réification?
  - 2. Décomposition de la fonction de cout!

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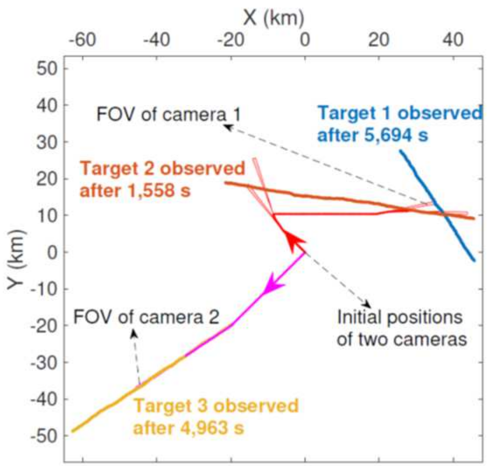
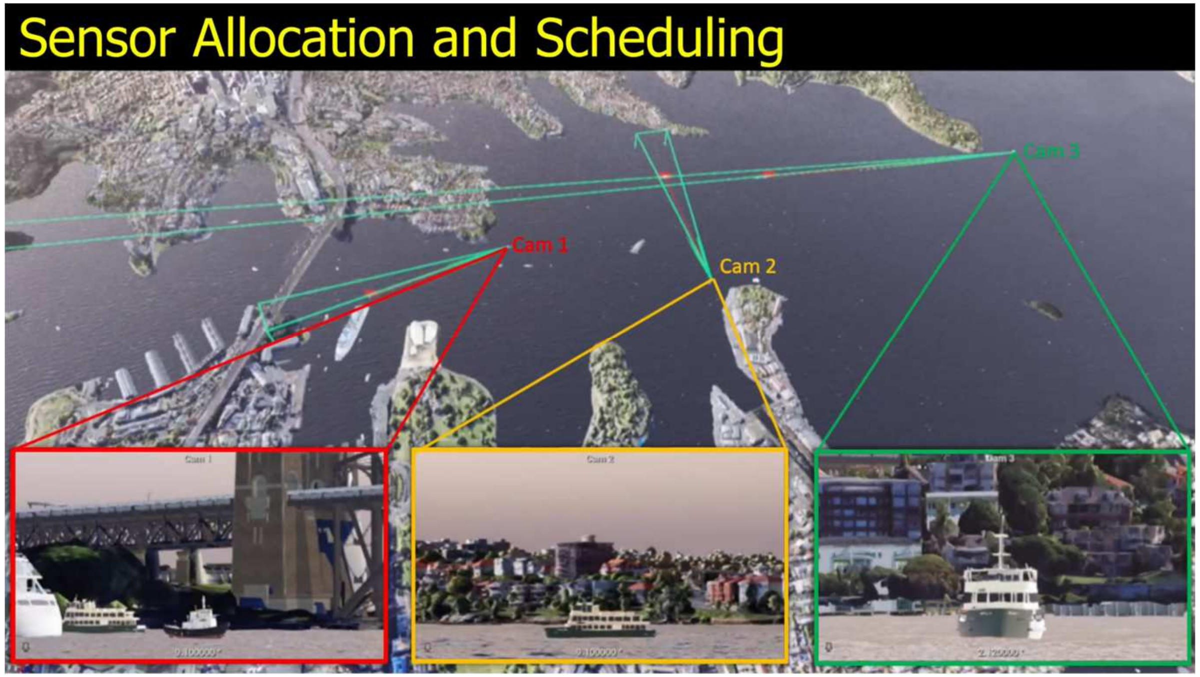
Situation Management in Maritime Domain

- **Edge computation for detection and tracking**
  - Domain adaptation for vision models
  - Active learning techniques

- **Planning and scheduling of observation**
  - Modèles hybrides
  - Gestion des occultations
  - Choix des actions: CP+matching regret cumulé+Equilibre corrélé entre agents





B. L. Nguyen et al., "Sensor Allocation and Online-Learning-Based Path Planning for Maritime Situational Awareness Enhancement: A Multi-Agent Approach," in IEEE Transactions on Intelligent Transportation Systems

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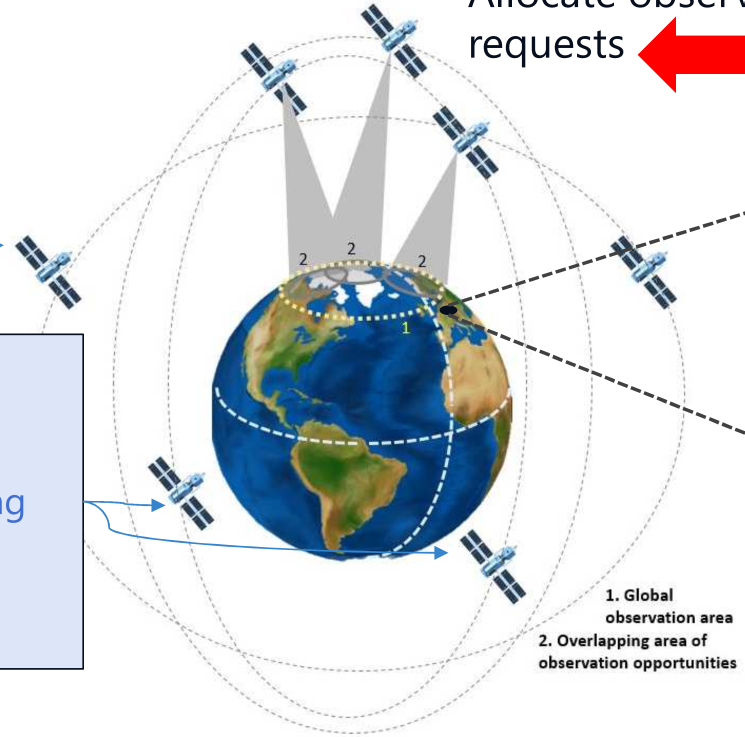
Problèmes d’observation distribuée

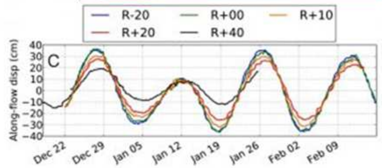
Allocate observation requests

Generate observation requests

Propulsion autonome



Contingencies and perturbations:
- AOCS
- On-board processing (ML Analytics)
- Upload/download windows



Data download with symbolic information

How to allocate observations to spacecraft ?
→ No centralized management, no single point of failure
→ Maximizing Performances, Availability, Resilience

Horizon Europe grant
Distributed AI for Edge

Optimisation sous contraintes distribuée (DCOP)

$$\forall r \in R \quad \sum_{s\in S, o\in O | p(o,s)=a^r} a(s,o,r) \leq 1$$

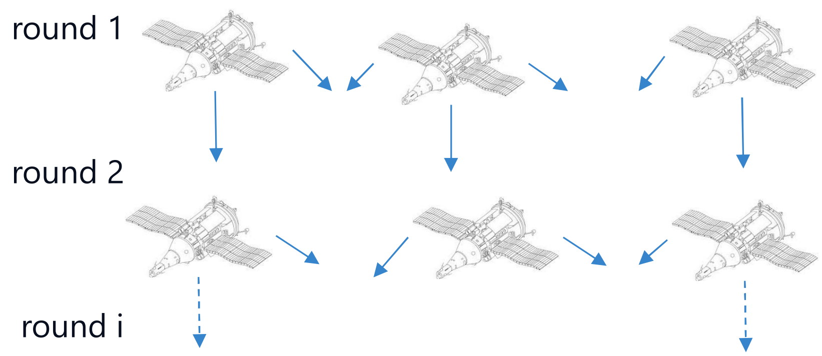
$$\forall r \in R,\ c^r \Leftrightarrow \sum_{s\in S, o\in O | p(o,s)=a^r} a(s,o,r) \leq 1$$

Asynchronous Weak Commitment

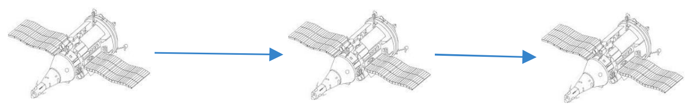
- Each spacecraft commits on its set of observation requests
- Whenever a request is not committed, the constraints is relaxed by others
- In practice use a reification of the coordination constraints (5,6) to implement the relaxation. Can also be a {0,1} variable.
- The list of commitment is monotonic increasing

Multiple rounds are performed between spacecraft

- Serialized or Parallel Execution, Synchronous / Asynchronous, Blocking/Non-blocking
- Tradeoff between information gain and spacecraft workload



Parallel execution



Serialised execution

Résultats préliminaires (spatial)

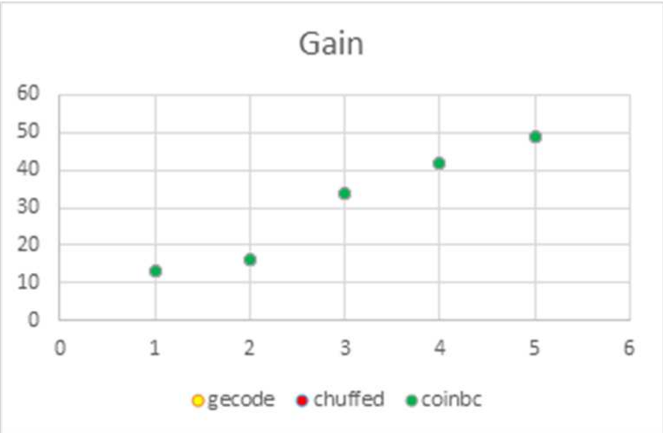
Implementation de AWC, sérialisée

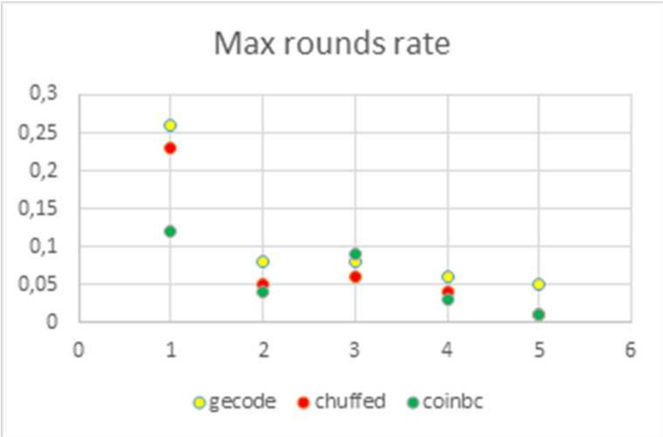
- 5 scenarios: 4,6,8,10,12 spacecraft, orbites polaires
- 1,5x spacecraft, number of requests, 100 instances
- execution sur les 5 scenarios

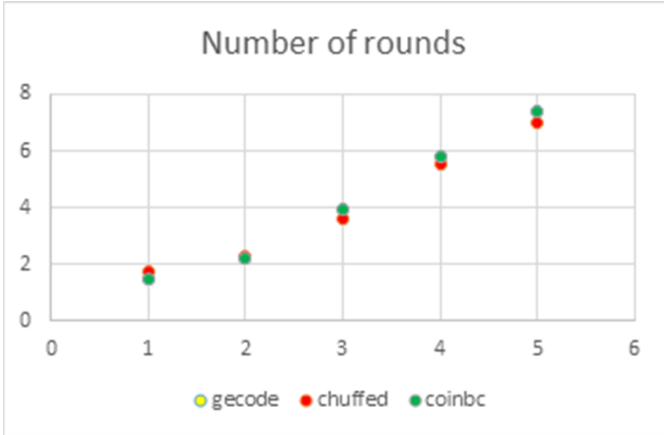
#rounds << #satellites

Comparaison croisée de solvers sous MiniZInc

- Chuffed: Constraint Propagator and Conflict Detection/Clause Learning
- COIN BC: Simplex implementation
- GeCode: Constraint Propagation







Statistically, COIN BC solve faster but need more rounds for convergence, even if the maximum rate is lower.

présenté à IEEE Space Mission Challenges for Information Technology
1st DISTRIBUTED AUTONOMY FOR SPACE SYSTEMS NASA WORKSHOP 2024

Discussion, Conclusion et Perspectives

Methodologie

- Extension des techniques de programmation par contraintes et de ML (hybridation, distribution)
- Relaxation et reification pour controller la resolution distribuée
- Approches aujourd'hui indépendantes de la technologie

Optimisation distribuée

- Combinaison de l'état de l'art entre DCOP et accord distribué
- Espace de conception trés importants
- Comparaisons à faire entre consensus, accord et DCOP, résultats unifies?
- Nombreuses propriétés liées à la distribution: réactiviré, sureté, confidentialité

Tactical Edge

- Traitement IA distribuée de bout en bout sans point unique de défaillance / vulnérablité
- Supporte des modèles complexes et le passage à l'échelle
- Mais difficultés avec des modèles de planification de plus en plus complexes (effets de l'incertitude)

IA de confiance et adaptative

Propriétés globales

Utilisation Responsable