Remote operations of fleets of autonomous robots

Challenges and approach

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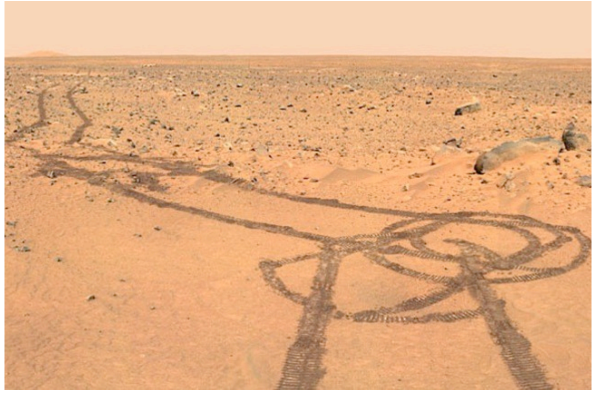
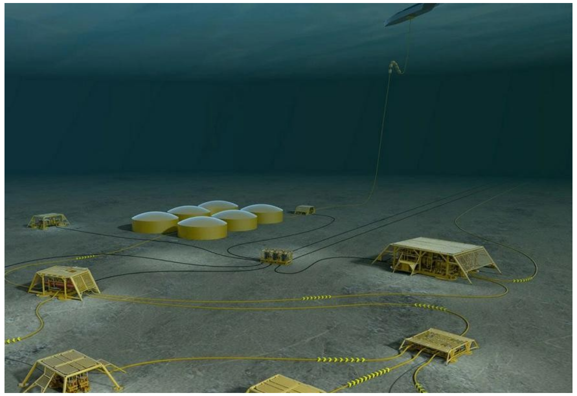
Remote operations

- Sites / areas where human presence is precluded





Either not possible, too risky or too costly for humans

Remote operations

- Sites / areas where human presence is precluded
- To do what ?

Considered missions:

- exploration, search
- coverage / patrolling: observations, scene analyses, situation assessment
- *interventions* in the environment

In various application contexts:

- Environment monitoring (pollutions, science, …)
- Search and rescue
- Civil security, defense applications
- …

➡ *Information gathering* and *intervention* missions

Outline

Remote operations

of

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Fleets of robots

- Advantages brought by robot teams
  - Increase of the achievable task and operation spaces
  - Higher robustness wrt. failures

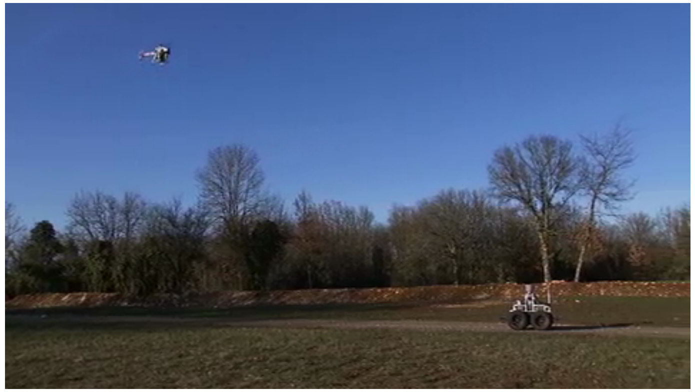
  - Complementarities
    ➙ Operational synergies
    ➙ Robotic synergies

Fleets of robots

- *E.g.* Air / Ground fleets of robots

"Remote eye" @ CMU

On going work @ ACFR

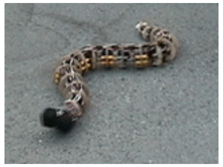


On going work @ LAAS & Onera

Fleets of robots

- *E.g.* Air / Ground fleets of robots
  - Ground robots





Good at:

- ✓ Precise information gathering
- ✓ Physical intervention
- ✓ Long duration missions
- ✓ Heavy load carrying

Not so good at:

- ✓ Global information gathering
- ✓ Self localization
- ✓ High speed mobility
- ✓ Avoiding hazards

- Aerial robots


Good at:

- ✓ Global information gathering
- ✓ High speed mobility
- ✓ Avoiding hazards
- ✓ Communication relaying

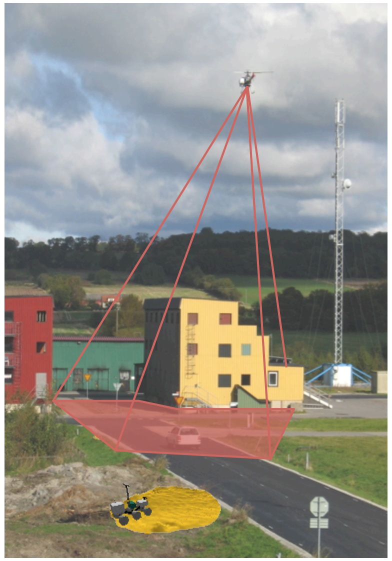
Not so good at:

- ✓ Long duration missions
- ✓ Physical intervention
- ✓ Heavy load carrying

Fleets of robots

- *E.g.* Air / Ground fleets of robots

  A variety of possible cooperation schemes:
  - UAVs assist UGVs
    - Localization
    - Communication relay
    - Environment modeling
  - UGVs assist UAVs
    - Detect clear landing areas
    - Carry on UAVs
    - Provide energy support
  - UAVs and UGVs cooperate to achieve a task / mission
    - Exploration
    - Monitoring
    - Intervention
    - …



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Operation of robot fleets

- No operators on site does not mean “no operators”
- Robot teams must not imply teams of operators !

➙ Cooperation / coordination issues must be solved by the robots

➙ A *high level* of autonomy is required

➙ (still low-level controls could be achieved by operators)

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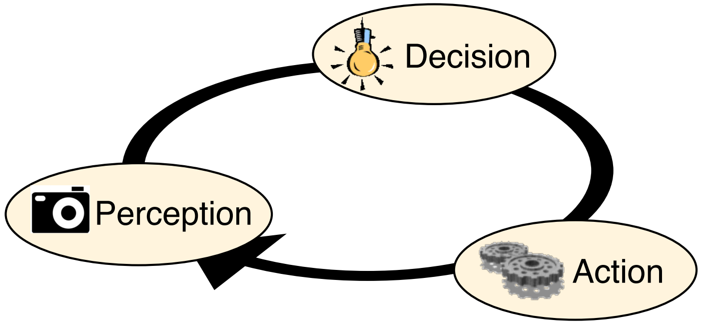
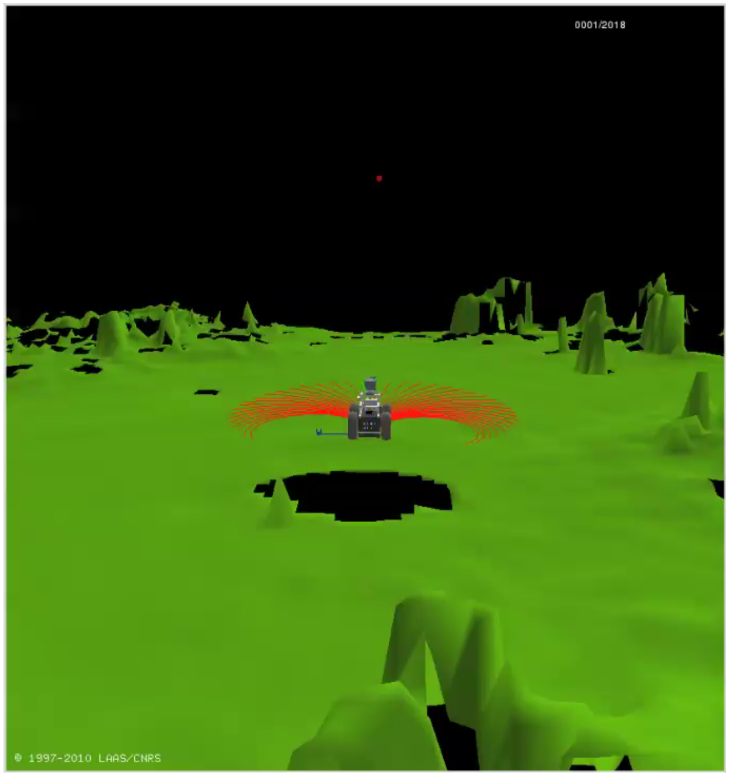
Autonomous robots

- The three pilars of autonomy

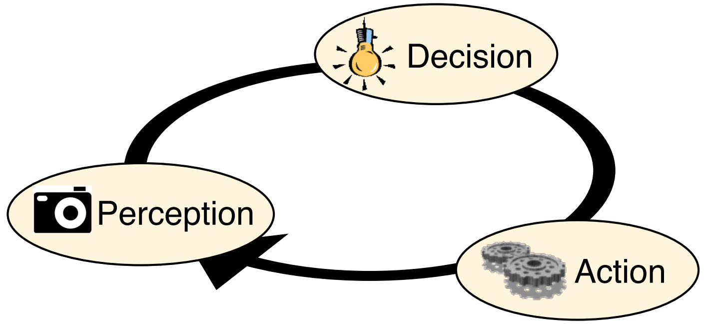


- A basic task: autonomous navigation



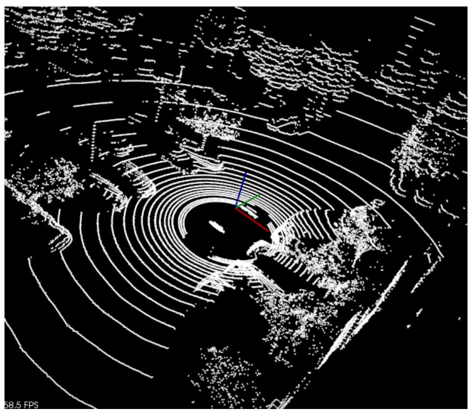
Autonomous robots

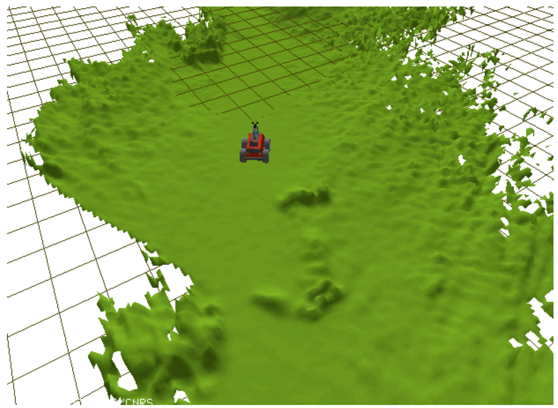
- The three pilars of autonomy



- A basic task: autonomous navigation

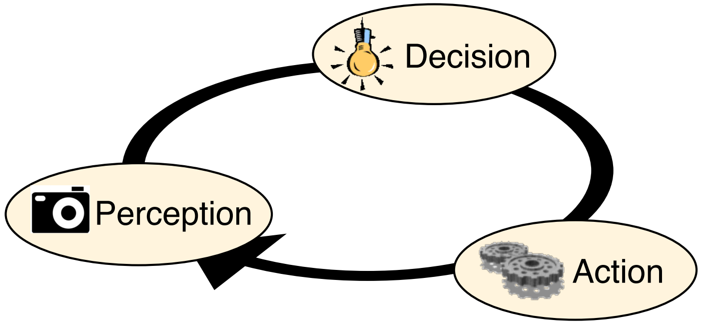
1. Perception


Depth image


Digital terrain model

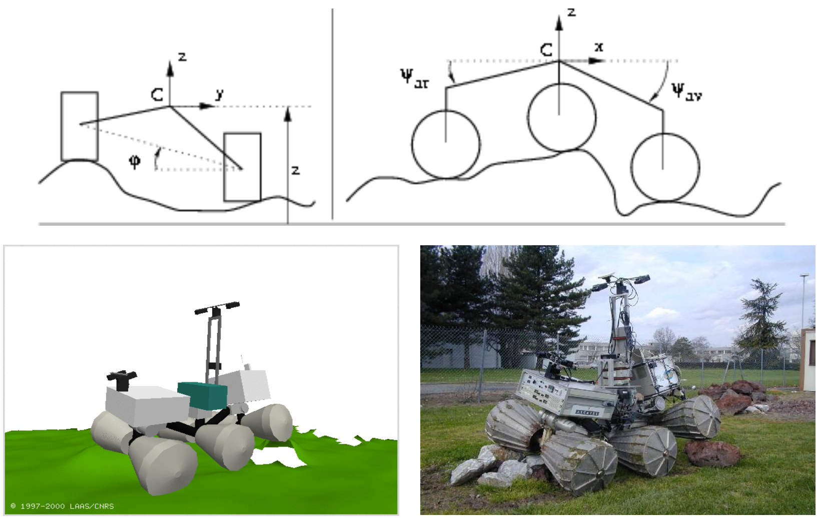
Autonomous robots

- The three pilars of autonomy

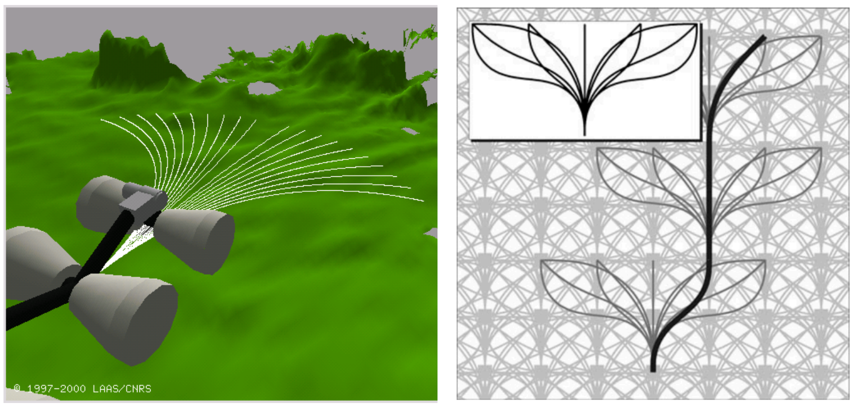


- A basic task: autonomous navigation

2. Decision



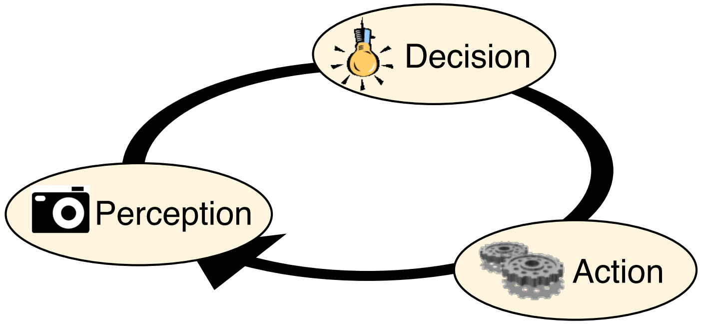
Convolution of the robot model with the terrain model



Search

Autonomous robots

- The three pilars of autonomy



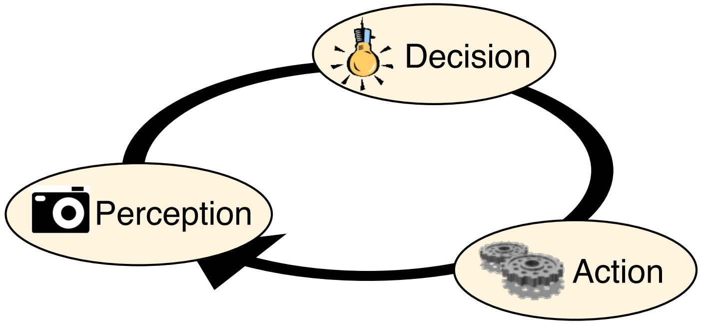
- A basic task: autonomous navigation

3. Action

“Just” execute the planned motions

Autonomous robots

- The three pilars of autonomy



2. Decision

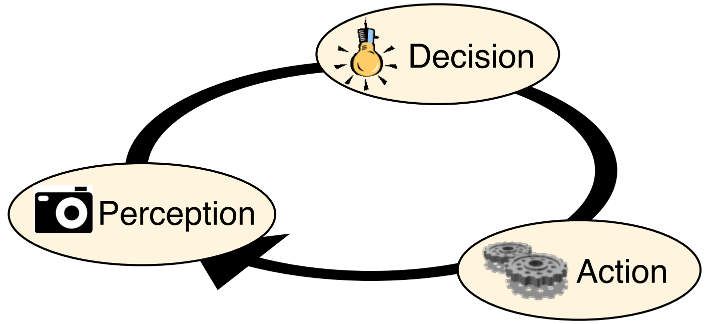
Deciding, Planning = Simulation + Search

• Simulation of the effects of an action with a predictive model

• Search over possible organizations of possible actions to meet a goal or to optimize a criteria

Autonomous robots

- The three pilars of autonomy



2. Decision

➡ Models are at the core of autonomy

- Action models
- Environment models

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and
approach

Challenges

Dozens of *heterogeneous* robots *cooperate* to achieve *long-lasting* missions in *large* environments

Large scale (*km*^{3}) implies:

- Faster robots, longer missions ("lifelong autonomy")
- Large (multi-scale) environment models
- Communication constraints
- Cooperative and coordinated perception / planning / action
- Operating robot fleets: need for advanced interactions

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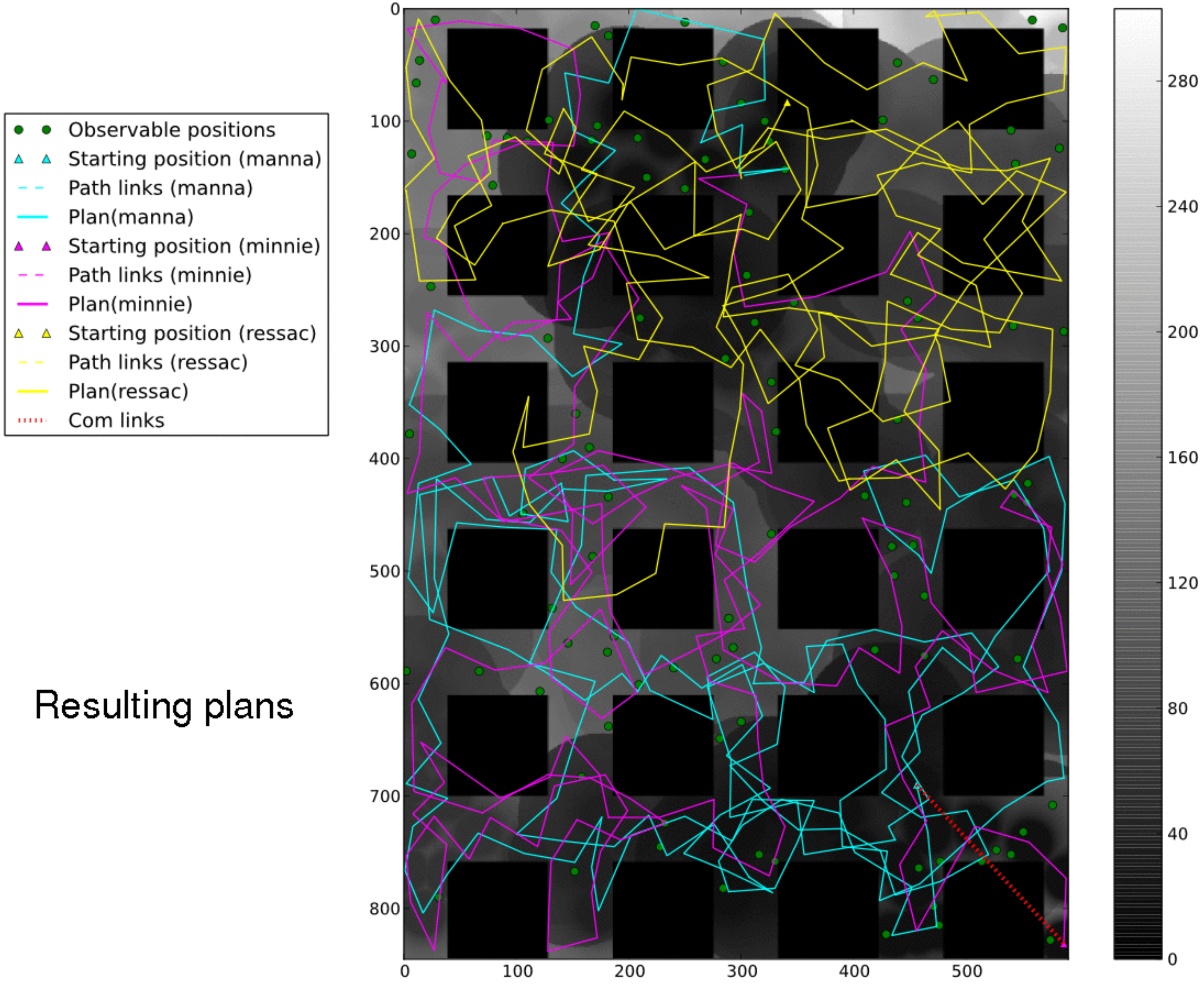
Approach (1/2)

Environment models are at the core of autonomy

➡ Environment models are at the core of cooperation

Illustration: planning a patrolling mission (1/2)

Illustration: planning a patrolling mission (2/2)



Resulting plans

What action models have been used?

- Robot motion model

$$nav\_time(R_i, C_j, C_k) \in [0, +\infty]$$

$$nav\_cost(R_i, C_j, C_k) \in [0, +\infty]$$

- Observation model

$$obs1(R_i, C_j) = \{C_1, ..., C_n\} \subset M_{R_i}, C_j \in M_{R_i}$$

$$obs\_utility(C_j) \in [0, 1], C_j \in M_{R_1} \cup ... \cup M_{R_n}$$

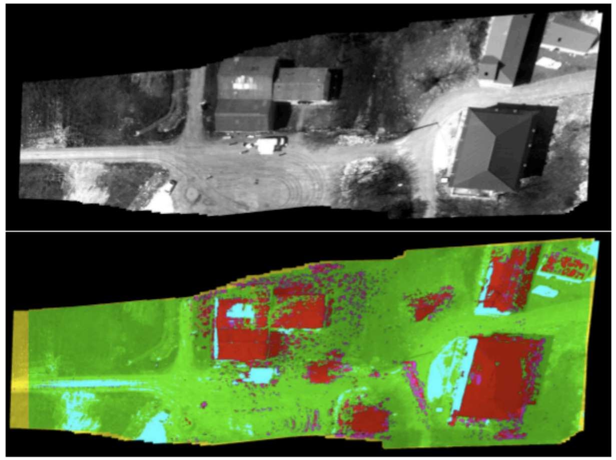
- Communication model

$$com(R_i, C_j) = \{C_1, ..., C_n\} \subset M_{R_i}, C_j \in M_{R_i}$$

$$com2D(R_i, C_i, R_j, C_j) \in \{0, 1\}$$

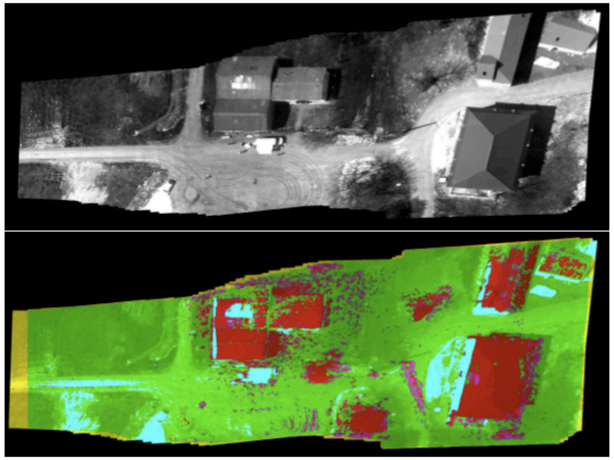
What environment models have been used?

- To plan motions: express traversability / accessibility

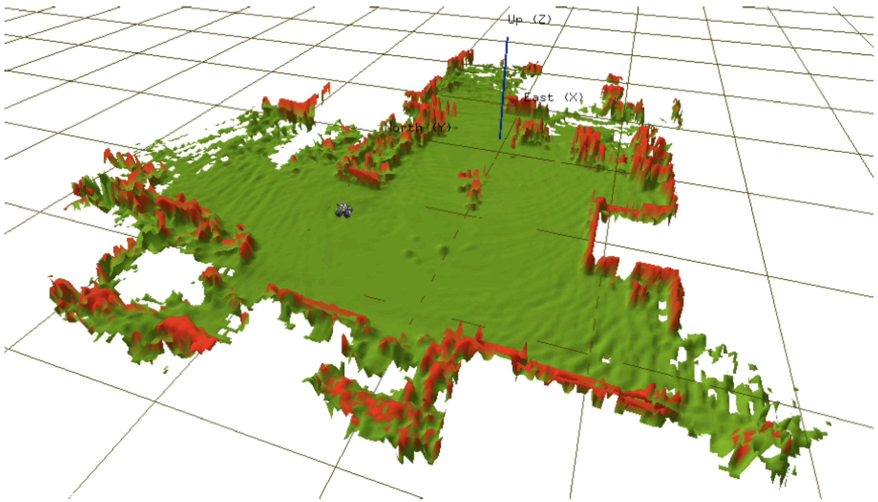


What environment models have been used?

- To plan motions: express traversability / accessibility



- To plan observations: line of sight visibility

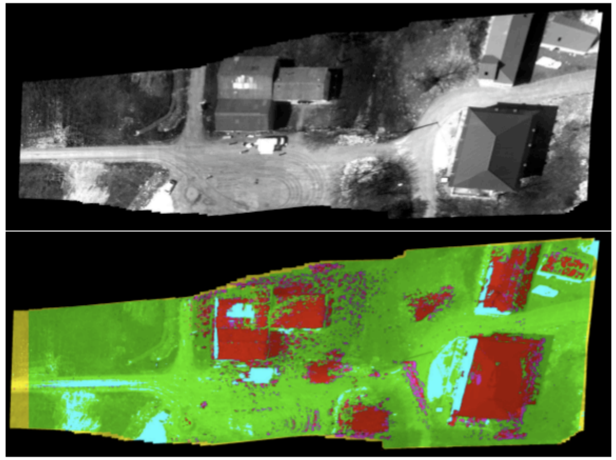


- To plan communications: line of sight visibility

Illustration: autonomous navigation revisited

What environment models have been used?

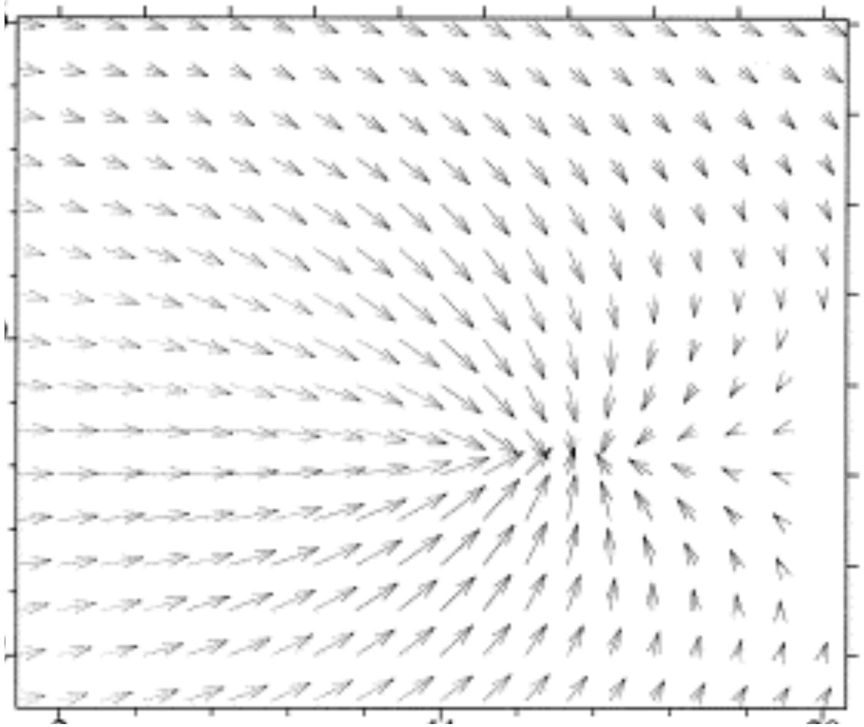
- To plan AGV motions: express traversability / accessibility



- To plan AUV motions: information quality (quantity) of the traversability model

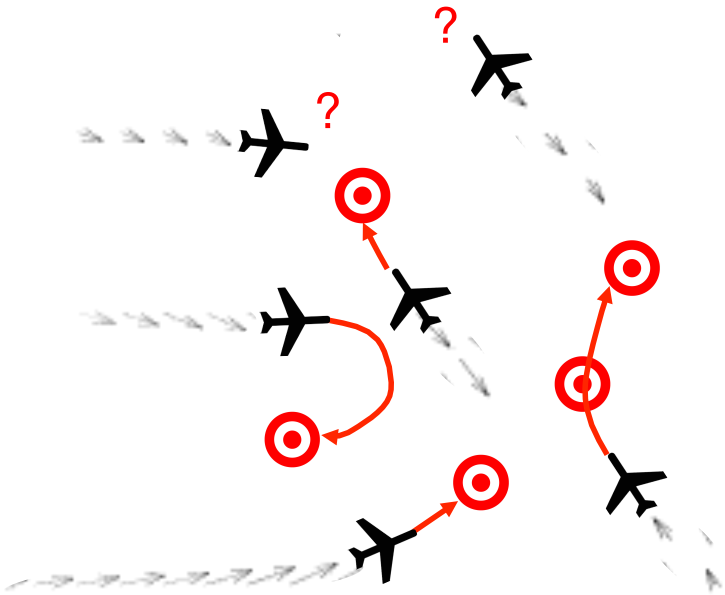
- Mission goal:
  - Characterize state of boundary layer below and surrounding a cloud
    - atmospheric stability, lifting condensation level, cloud updraft
  - Follow 4D evolution of the cloud
    - entrainment at edge, liquid water, cloud microphysical properties
- 4D adaptive sampling
  - Servo on the gathered information to gain more information
  - Optimize the drones trajectories (trade-off: explore vs. sustain)

- A *dynamic* phenomenon…
- … observed *locally*



"Air truth"

- A *dynamic* phenomenon…
- … observed *locally*



Known information
at time *t*

1. Where to gather
   new information?
2. Who is flying
   where? And how?

- What environment model is used?
  - "Generic" physical model of the cloud…
  - … dynamically updated

  - Winds ~ traversability
  - Quality / quantity of information drives the sampling

Where do environment models come from?

- A priori models
  - Orthoimages, digital terrain maps
  - CAD models
  - …
- Models built online
  - Robot localisation is a key

On the importance of localization

Localization is required to:

- Ensure the achievement of the missions, most often defined in localization tems ("`goto [goal]`", "`explore / monitor [area]`", ...)

- Ensure the lowest level (locomotion) controls

- Ensure the proper execution of paths / trajectories

- Ensure the spatial consistency of the built models

Localization solutions

A variety of available information:

- Motion sensors
  Odometry, IMU, velocimeters, …
- Environment sensors
  Lidar, camera(s), radar, …
- Infrastructure sensors
  GPS, radio receivers, …
- A priori information
  Motion models, environment models (maps), …

Localization solutions

A variety of available techniques:

- Dead-reckoning
- Map-based localization
- Simultaneous Localization and Mapping (“SLAM”)

But… what localization?

Essential questions to answer:

1. With which precision? — From *cm* to *meters*
2. In which frame? — Absolute vs. local
3. At which frequency? — From *kHz* to "sometimes"
4. *Integrity* of the solution?
5. *Disponibility* of the solution?

cm accuracy, > 100 *Hz*, local frame:

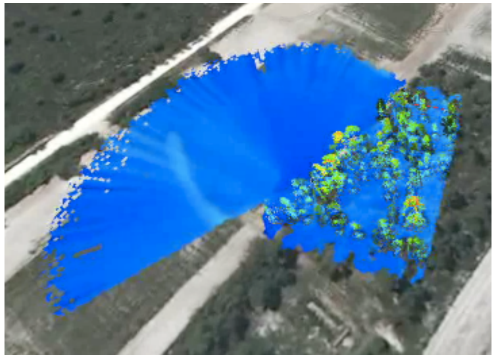
- Ensure the lowest level (locomotion) controls
- Ensure the proper execution of paths / trajectories
- <u>Ensure the spatial consistency of the built models</u>

~*m* accuracy, "sometimes", global frame:

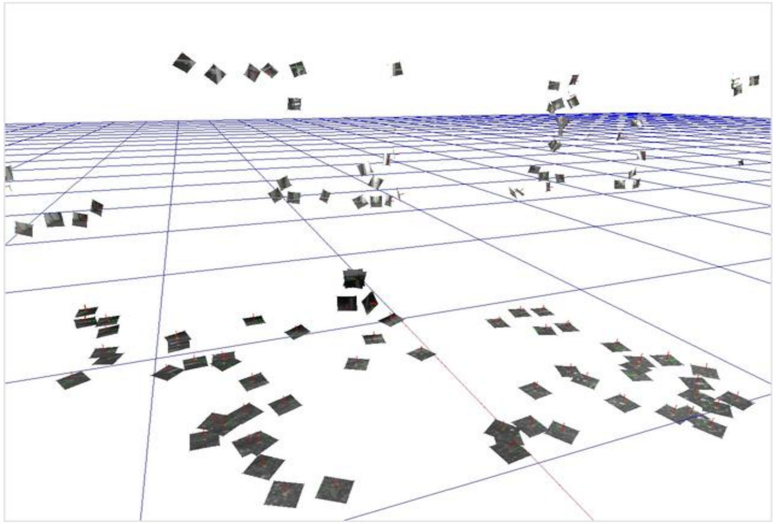
- Ensure the achievement of the missions, most often defined in localization terms ("`goto [goal]`", "`explore / monitor [area]`", …)

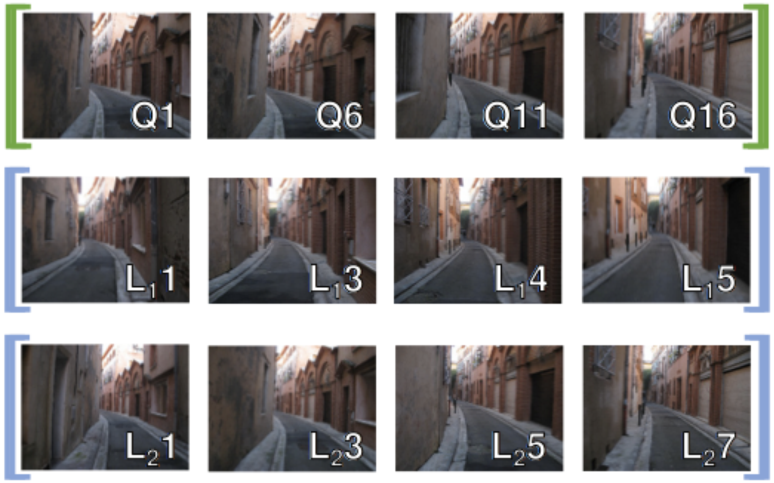
What environment models are used for localisation?

- Geometric models (a priori of built by the robots)



- Dedicated models (*e.g.* “landmarks”, “views memory”)

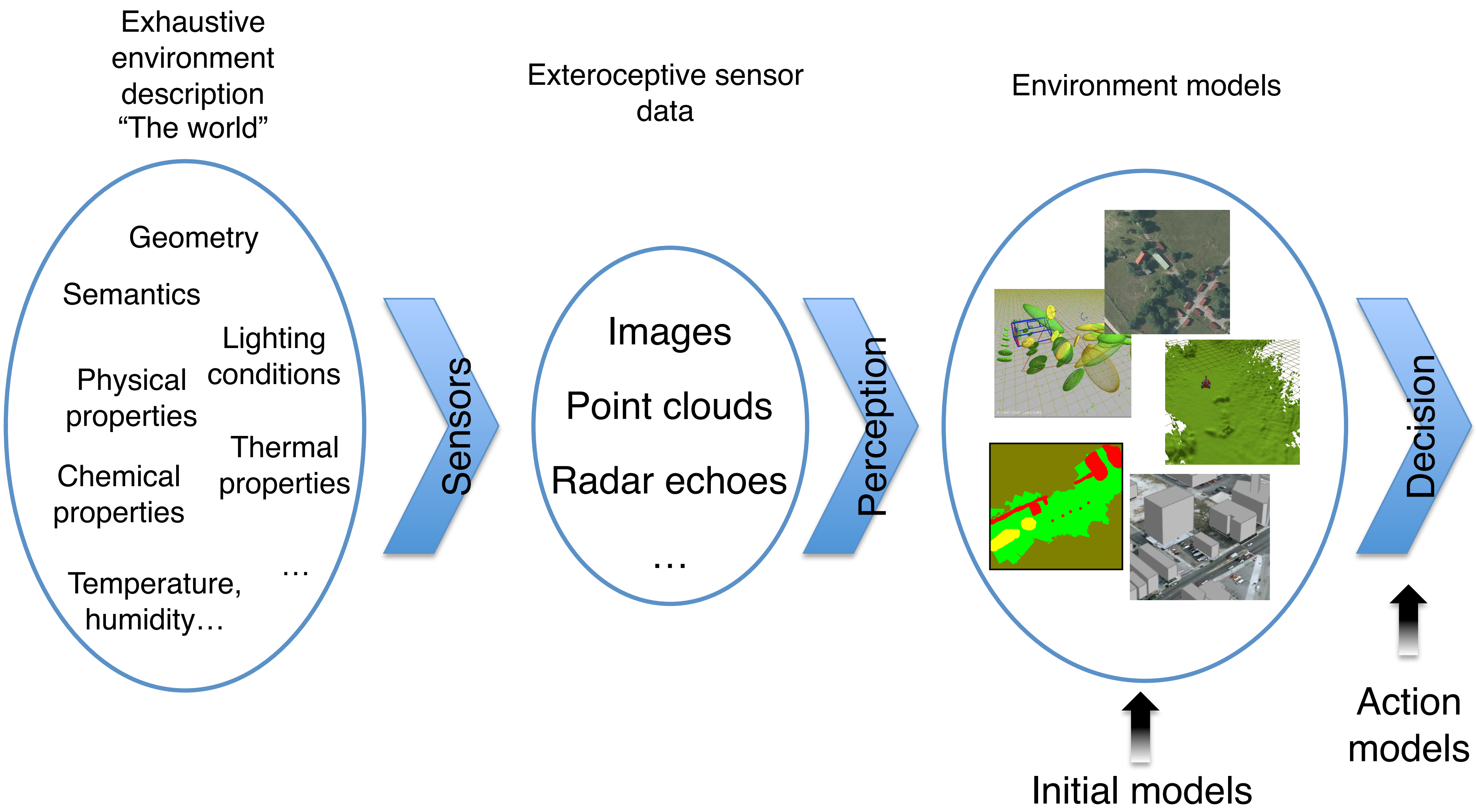




Wrap up: a patrolling mission

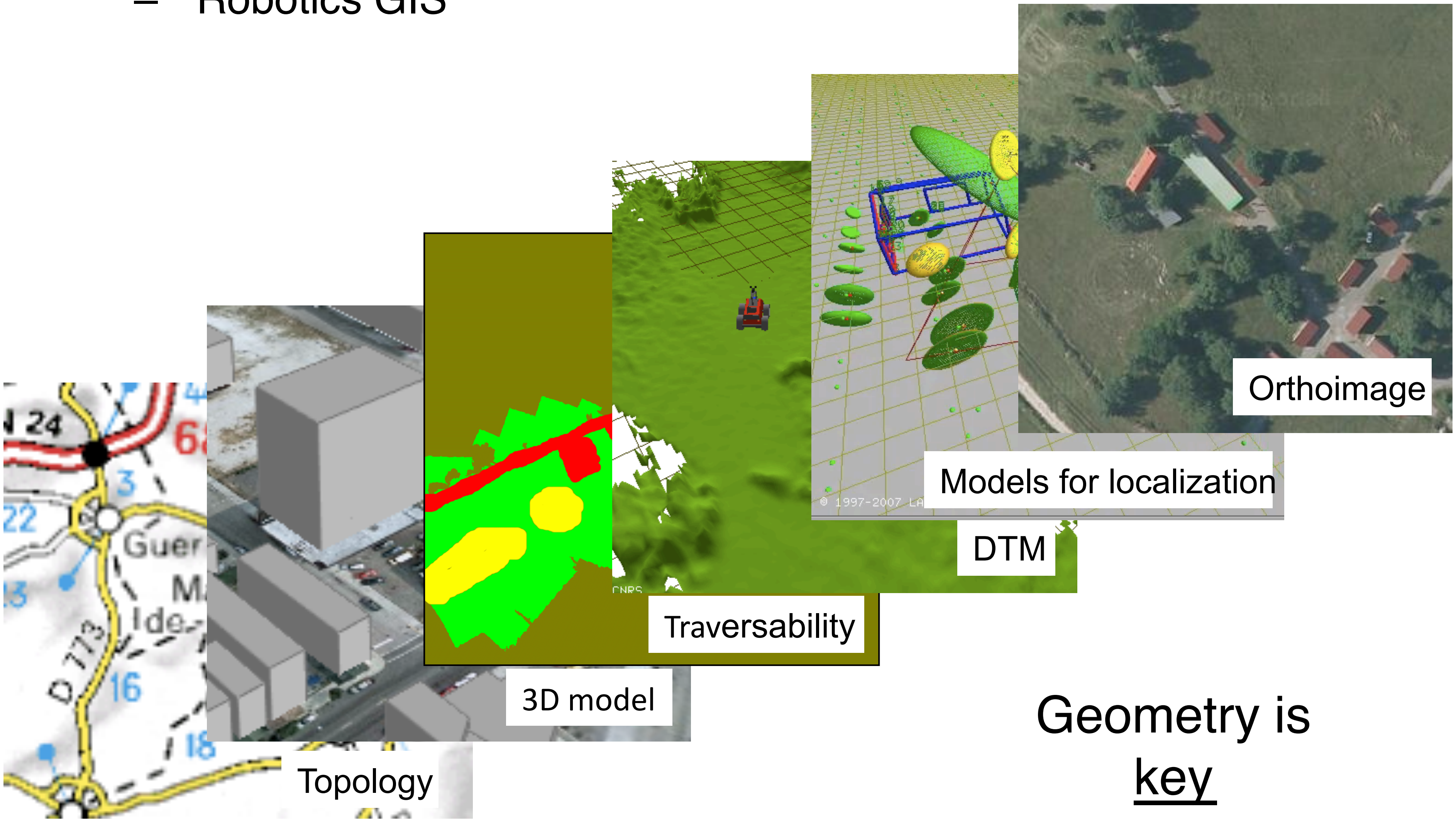
Summary on environment models

- Information flow



Managing environment models

- A variety of *dedicated* models has to be maintained
  - "Robotics GIS"

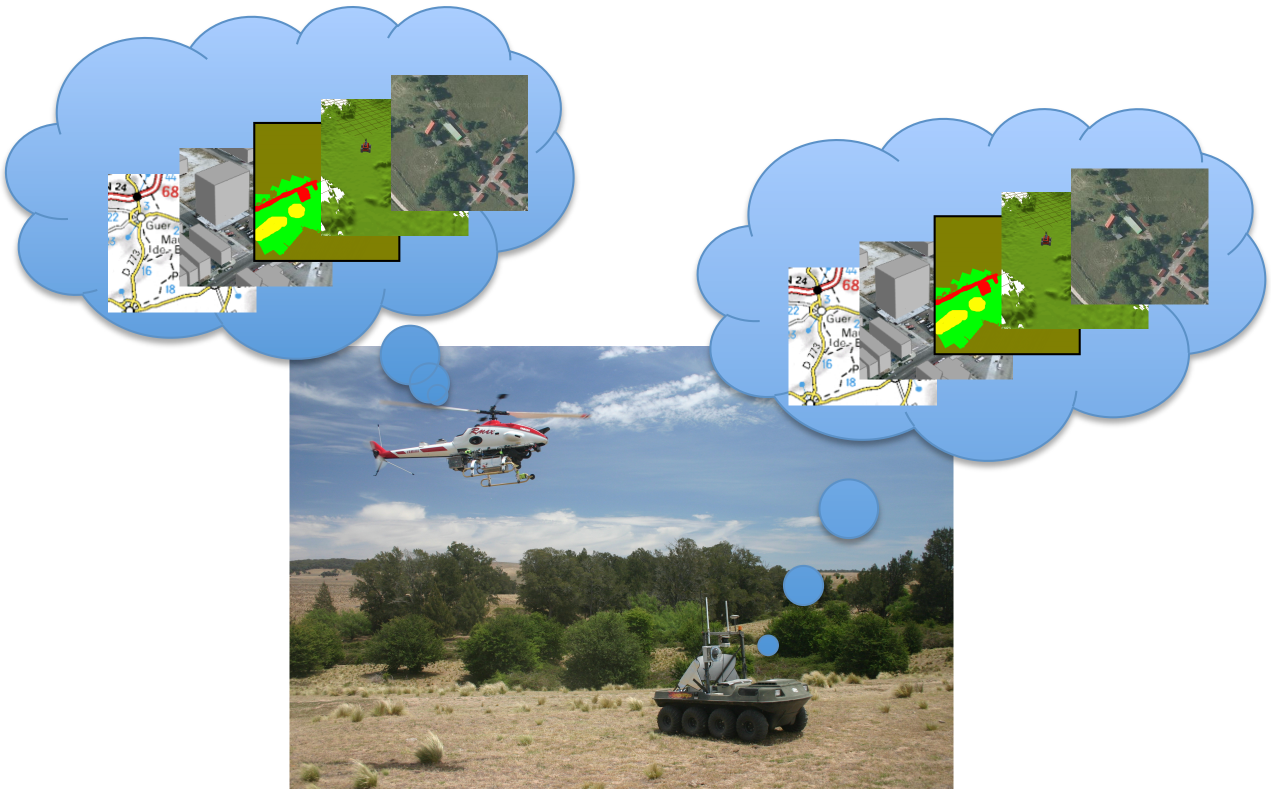


Geometry is <u>key</u>

Managing environment models within a team

Distributed models management:

- APIs for clients
- Maintain the inter-robot inter-model consistency



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Approach (2/2)

Environment models are at the core of autonomy

➡ Environment models are at the core of cooperation

➡ Environment models are at the core of operator interactions

Conclusions

- Most often, having the required information is having solved the problem
  - ➙ Numerous tasks / missions can be turned into of information gathering approaches
- Autonomous robots (robot teams) are info-centric systems
  - ➙ Key-role of environment representations
- Info-centric view + operator control impacts the overall system architecture
  - ➙ "Resource oriented architecture"
  - ➙ Operator / robot information sharing: spatial ontologies?
  - ➙ (plus: adjustable autonomy)