

WG P1872.2 Ontologies for Autonomous Robotics

Agent Behaviors and The belief–desire–intention (BDI) model

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Outline

- Agent Behaviors
- BDI Model

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- BDI Model

- **Robot Behavior**

Behavior is what an external observer sees a robot doing.

Behavior is a result of a sequence of robot actions triggered by a key stimulus.

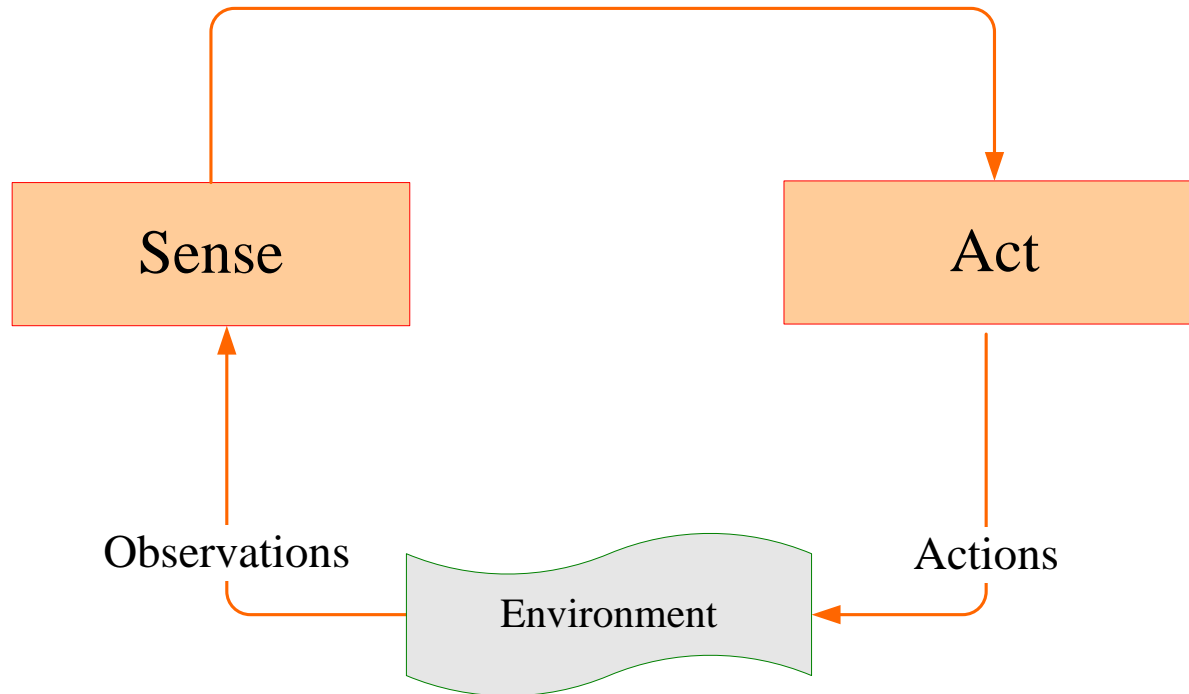
Behavior is mapping of sensory input to actions.



- **Robot Behavior**
 - Reactive Behavior
 - Deliberative Behavior
 - Cognitive Behavior
 - Emergent Behavior

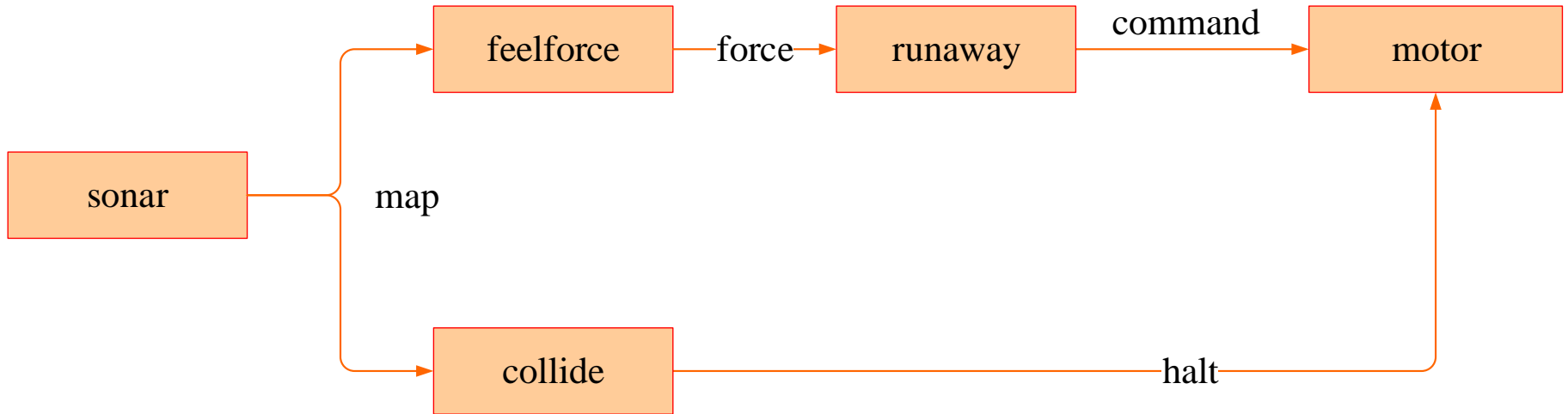
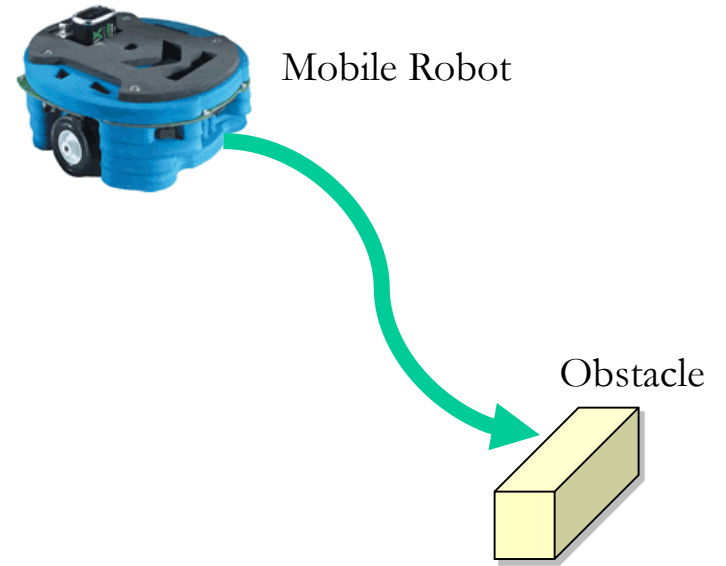
- **Reactive Behavior**

Reactive agents react to changes in the environment without explicitly reasoning about it.



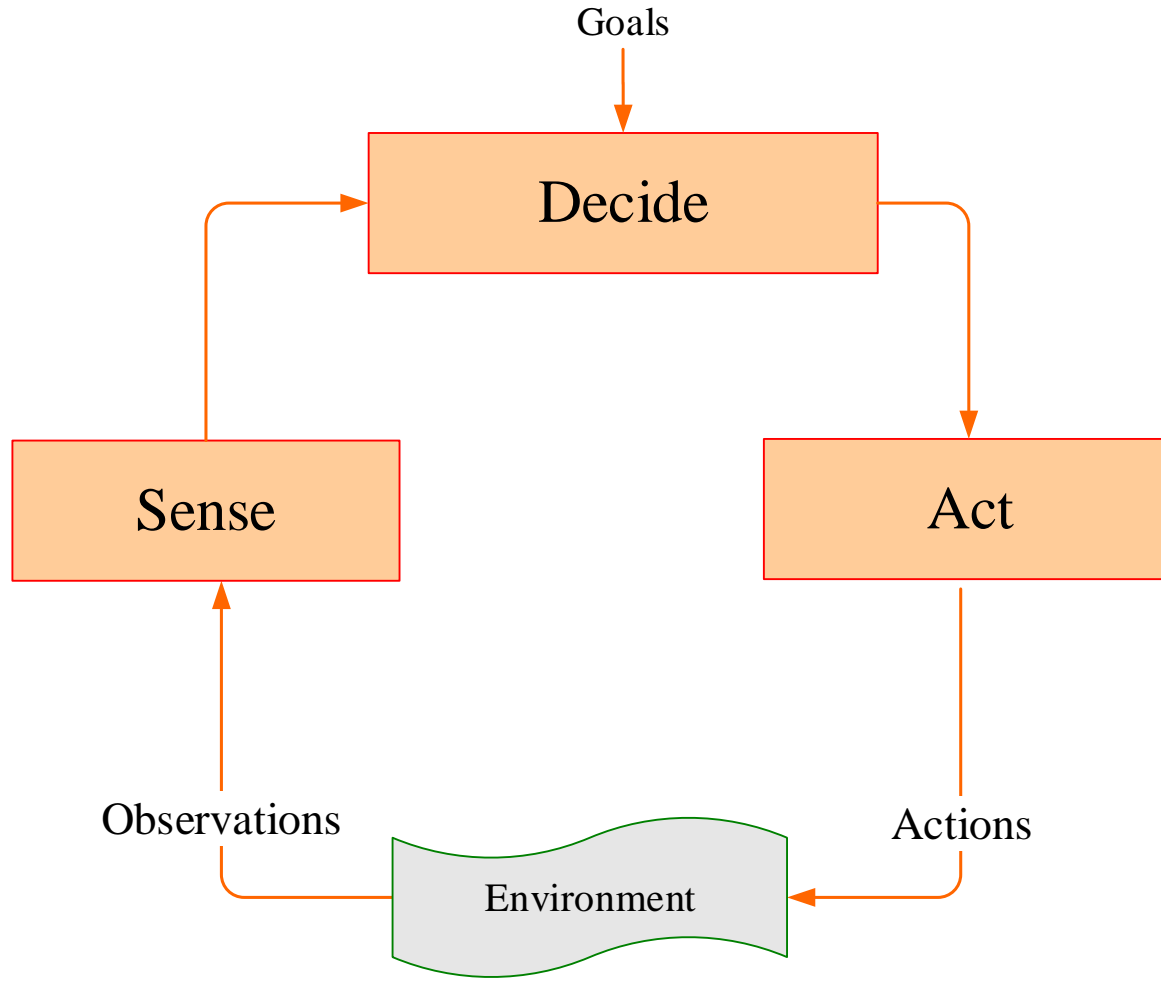
- Reactive Behavior

Runs away if approached, avoids obstacles

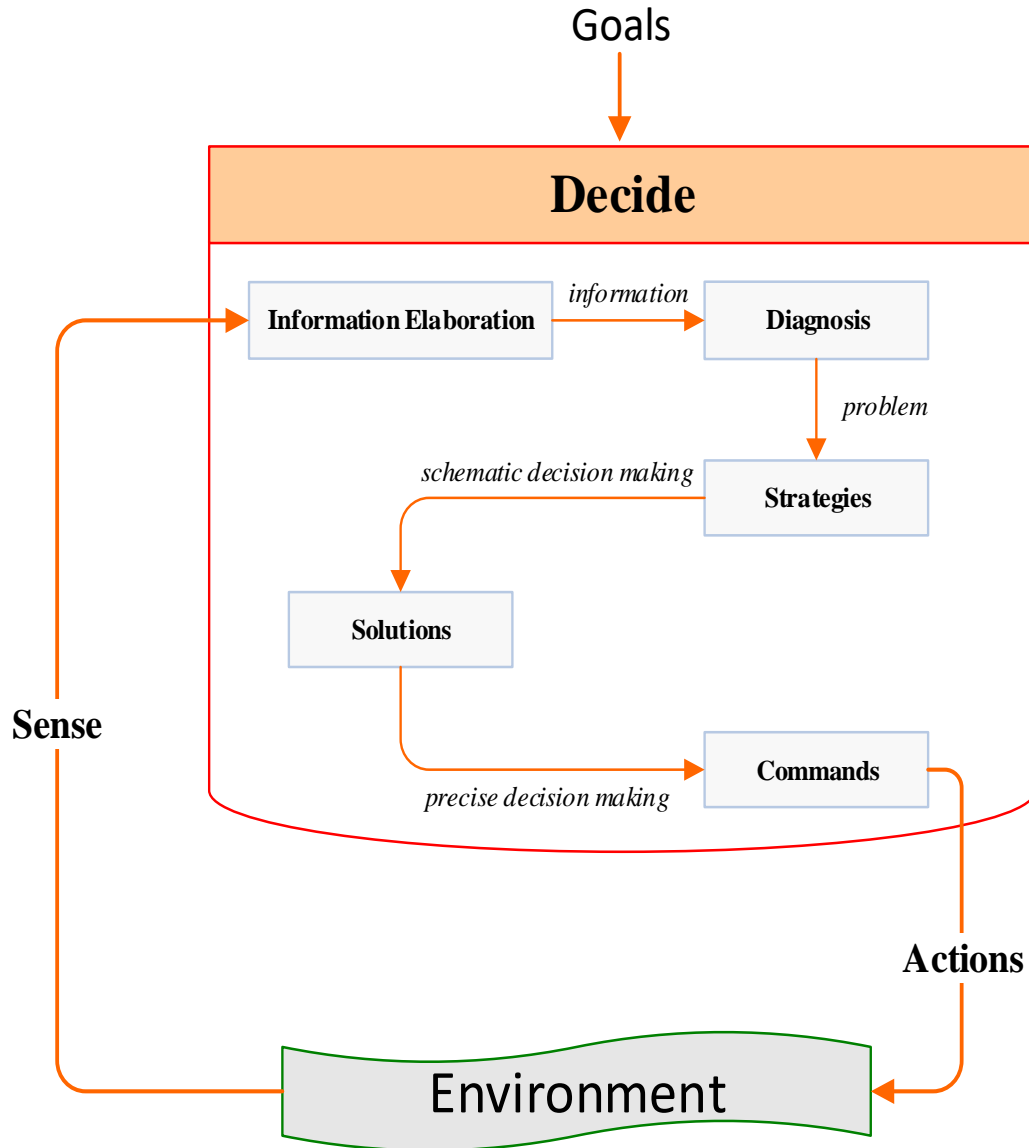


Agent Behaviors

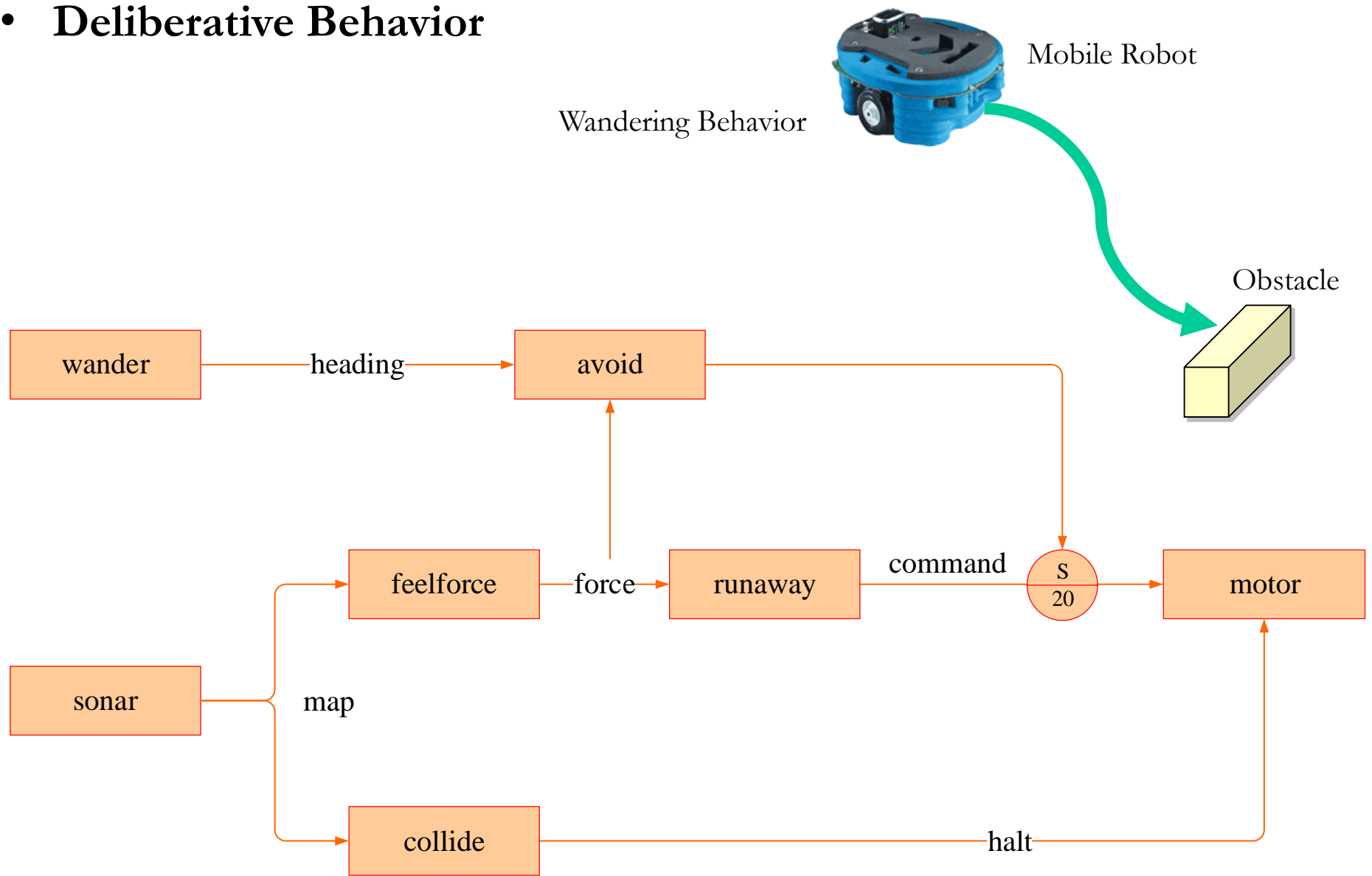
- Deliberative Behavior



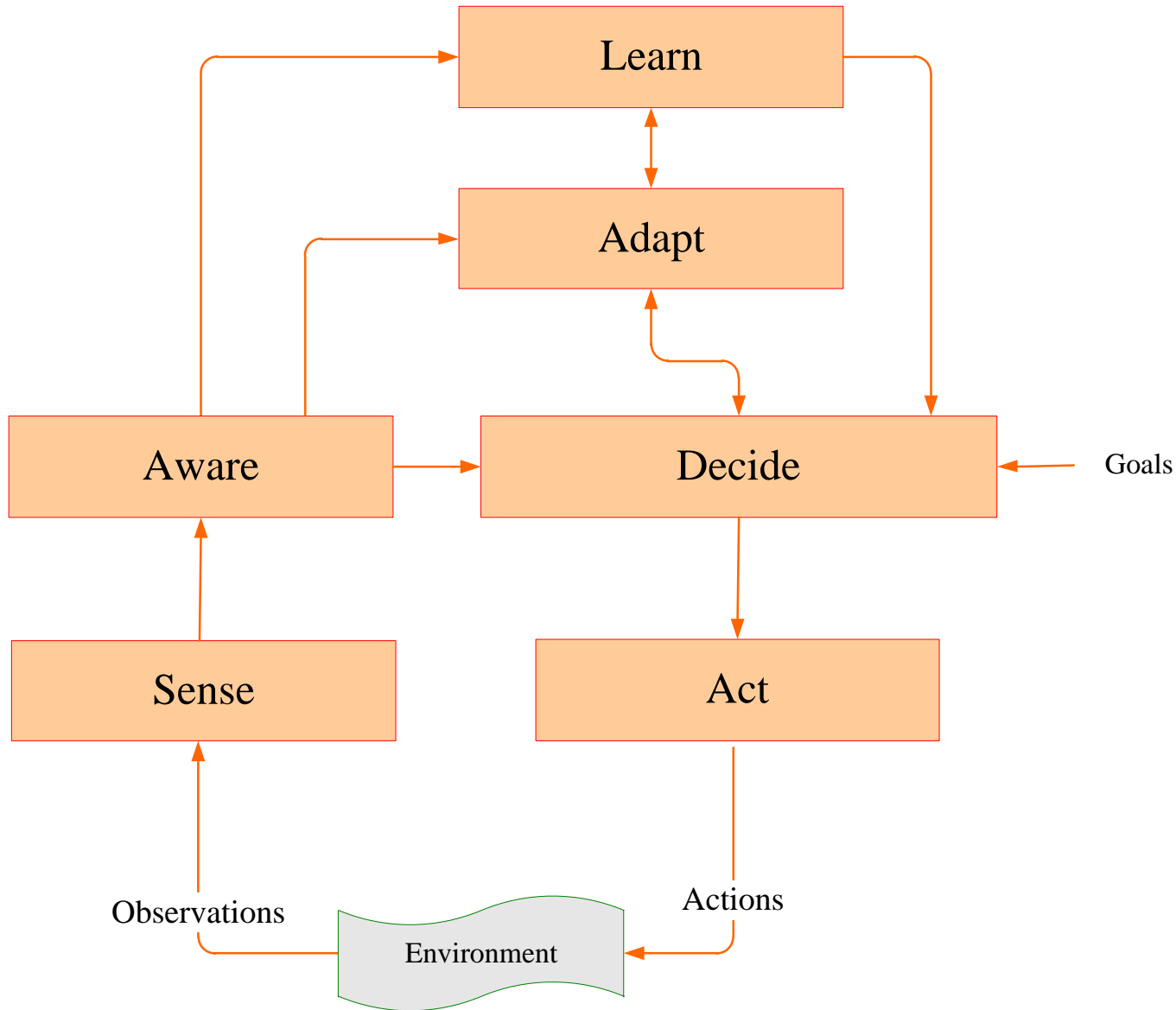
- Deliberative Behavior



- Deliberative Behavior



- Cognitive Behavior

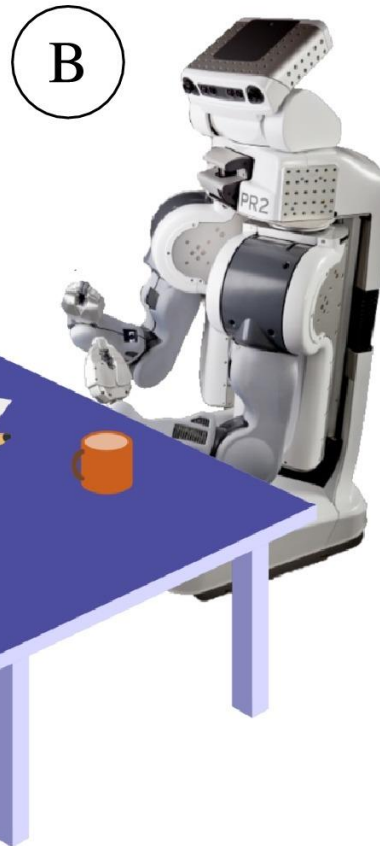


- Cognitive Behavior**

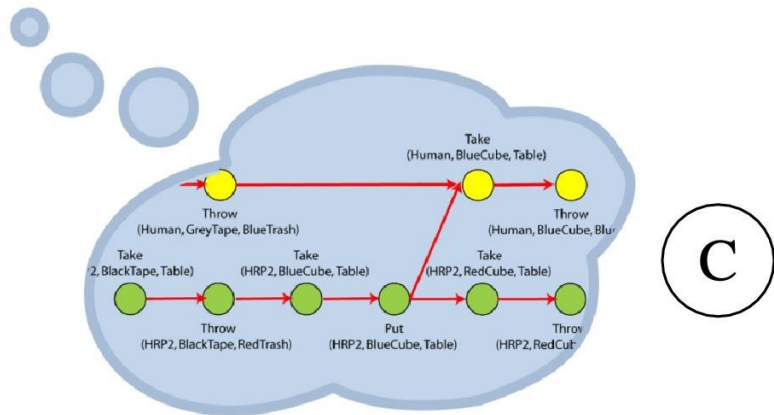
Sources of information are multi-modal dialogue



Perspective-aware monitoring of the environment and human activity

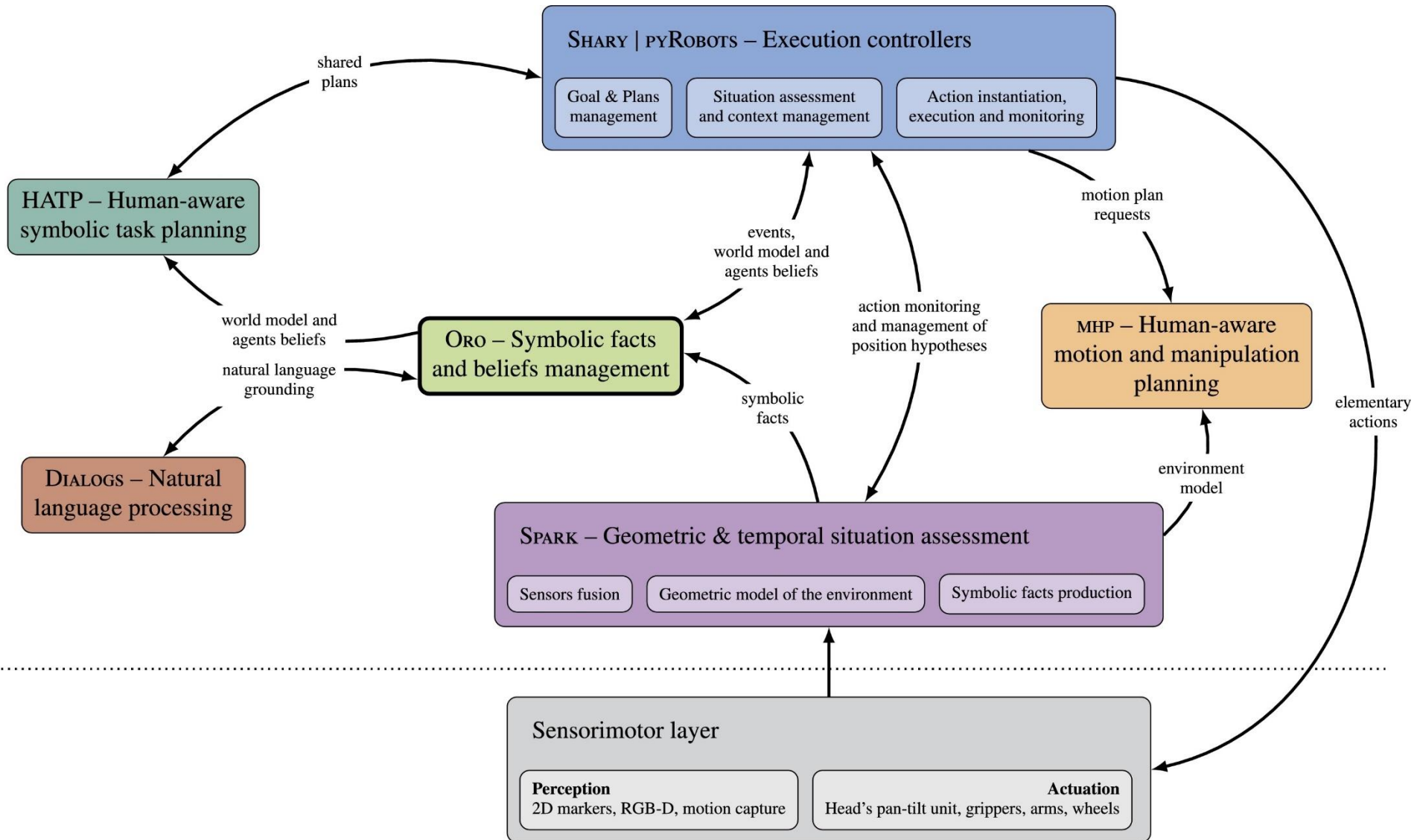


The robot explicitly reasons on the fact that it is (or is not) observed by the human. Reasoning and planning take into account agents beliefs, perspectives and capabilities (D) as estimated by the robot.



The robot must adapt on-line its behaviors by merging computed plans (C) with reactive control

- Cognitive Behavior



- **Emergent Behavior**

“**Collective behavior is not simply the sum of each participant’s behavior**, as others emerge at the society level”. [1]

Emergent behavior cannot be predicted through analysis at any level simpler than that of the system as a whole... Emergent behavior, by definition, is what’s left after everything else has been explained” [2]

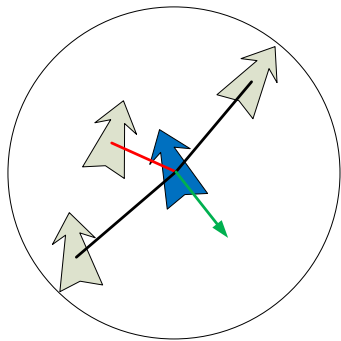
Emergent behavior is the behavior that emerges from the combined dynamic actions and reactions by individual agents.

[1] Pasteels, J. and Deneubourg, J., (Eds.) (1987), From Individual to Collective Behavior in Social Insects, Birkhauser.

[2] Dyson & George B. (1997). Darwin Among the Machines: The Evolution of Global Intelligence. Perseus Book Group

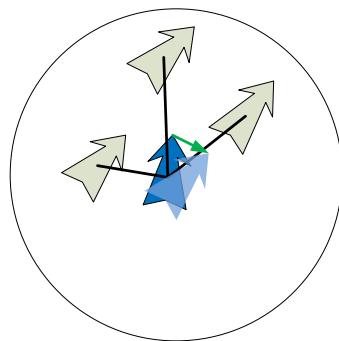
- **Self-organization as an Emergent Behavior**

Self-organizing formation is an emergent process of making whole forms by local interactions of distributed simple autonomous elements without global information at all and without depending on the initial position and orientation of the elements.



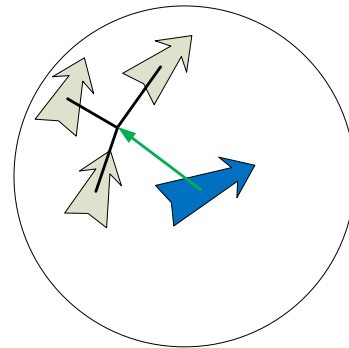
Separation

avoid crowding
neighbors



Alignment

steer towards average
heading of
neighbors



Coherence

steer towards
average position of
neighbors

*Staying together but not
colliding*



Outline

- Agent Behaviors
- **BDI Model**

The Belief-Design-Intention (BDI) model is based on Bratman's theory of **practical reasoning**.

“**Practical reasoning** is a matter of weighing conflicting considerations for and against competing options, where the relevant considerations are provided by what the agent desires/values/cares about and what the agent believes”

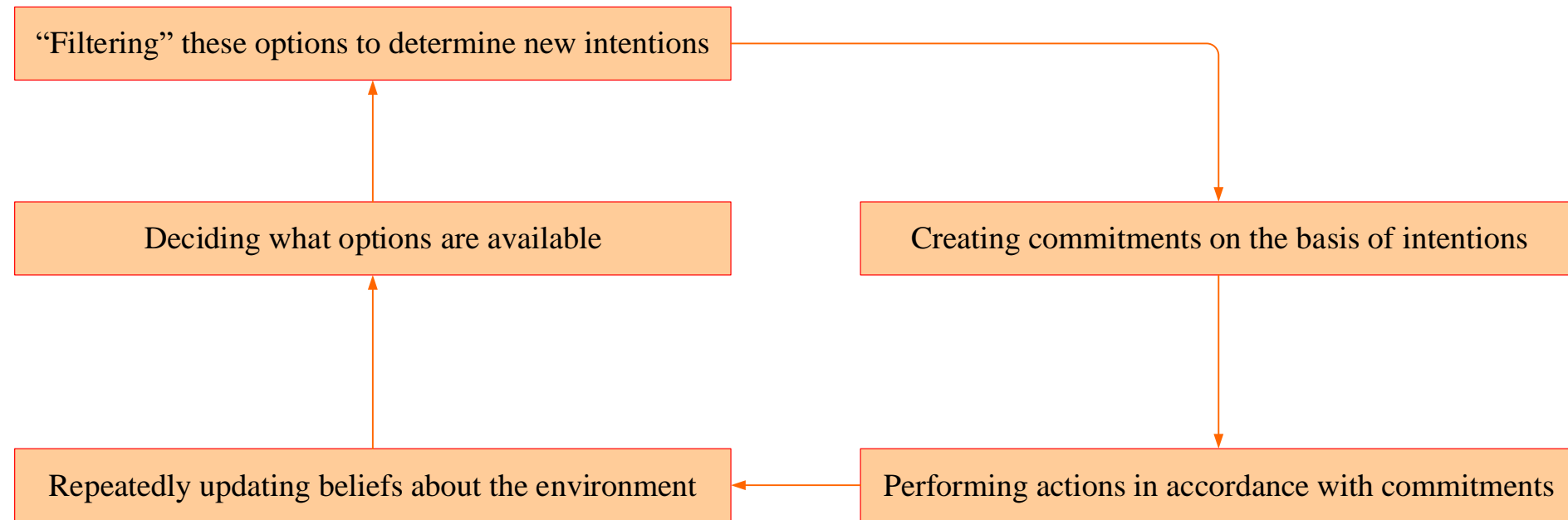
Bratman, M. (1990), “What is intention?”, In Cohen, P. R., Morgan, J. L., and Pollack, M. E., editors, *Intentions in Communication*, pages 15–32. MIT Press, Cambridge, MA.

The **practical reasoning** involves two important processes:

- **Deliberation:** the process of deciding what goals we want to achieve.
- **Means-ends reasoning:** addresses how we are going to achieve these goals.

Dunin-Keplicz and Verbrugge define practical reasoning as form of reasoning that is aimed at conduct rather than knowledge.

The cycle of this reasoning involves [1]:

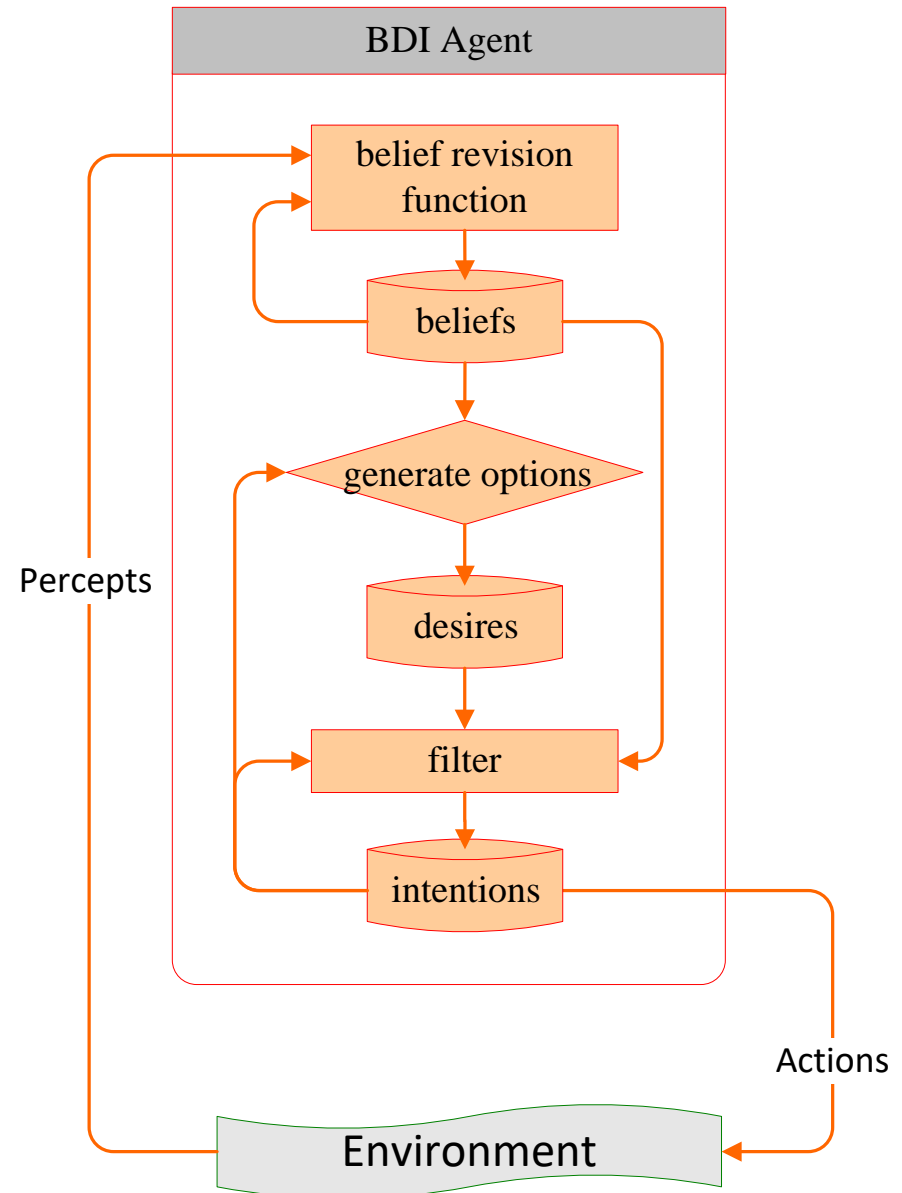


Bratman sees belief, desire, and intention as mental attitudes, that generate human action.

- **Beliefs** capture **informational** attitudes and represent agent's knowledge.
- **Desires** represent the **motivational** attitudes or agent's goals. A goal is typically a description of a desired state of the environment. The desires provide the agent with motivations to act.
- **Intentions** are the **deliberative** attitudes of agents.

A BDI agent has:

- **Beliefs** about itself, other agents and its environment,
- **Desires** about future states (i.e., goals) and
- **Intentions** about its own future actions (i.e. plans).



- **Example**

Beliefs and desires shape the intentions that agents adopt.

- I believe that if I use Hands-free Driving (Super Cruise) I will enjoy the ride
- I desire to enjoy the ride
- I intend to use Super Cruise



This is a modified version of another example given in Yang-AiLab-2008-Agent Technology in the context of passing a course

- **Beliefs**

Steps to activate Super Cruise

- *ACC*: Turn on Adaptive Cruise Control (*ACC*)
- *Wait*: wait until steering wheel icon turns white
- *Press*: when it is safe to do so, press the steering wheel-mounted Super Cruise button.

$$Belief_1 = brf \left\{ \Phi, \left\{ \begin{array}{l} SuperCruise \rightarrow enjoyRide \\ ACC \cap Wait \cap Press \rightarrow SuperCruise \text{ activated} \end{array} \right\} \right\}$$

- **Intention**

The agent has an initial intention to enjoy the ride.

$$Intentions_0 = \{enjoyRide\}$$

- **Desire**

The agent's desires are freshly generated each for cycle (they do not persist). The option generation function leads to desires to pass the course and its consequence:

$$Desires_1 = options(Belief_1, Intentions_0) = \{ACC, Wait, Press\}$$

- **Filter**

The filter function leads to some new intentions being added:

$$\text{Intentions}_1 = \text{filter}(\text{Belief}_1, \text{Desires}_1, \text{Intentions}_0) = \{\text{enjoyRide}, \text{Activate SuperCruise}, \text{ACC}, \text{Wait}, \text{Press}\}$$

One or more of these intentions will then be executed before the agent's deliberation cycle recommences.

- **Belief Revision**

Suppose the agent perceives new information which leads to his beliefs being revised:

Belief₂

$= \text{brf} \left\{ \text{Belief}_1, \left\{ \begin{array}{l} \text{aggressiveDriving} \rightarrow \text{enjoyRide} \\ \text{aggressiveDriving} \rightarrow \text{arrive faster and more excitement} \end{array} \right\} \right\}$

$= \text{brf} \{ \text{SuperCruise} \rightarrow \text{enjoyRide}, \text{ACC} \cap \text{Wait} \cap \text{Press} \\ \rightarrow \text{SuperCruise activated}, \text{aggressiveDriving} \}$

- **Generate Options**

Revising desires and intentions:

$$Desires_2 = options(Belief_1, Intentions_1) = \{aggressiveDriving\}$$

$$Intentions_2 = filter(Belief_2, Desires_2, Intentions_1) = \{enjoyRide, aggressiveDriving\}$$

The agent drops his original intention to use SuperCruise (and its consequences) and adopts a new one to drive aggressively.

- **Belief Revision**

Subsequently, the agent perceives that if he aggressively drives, he will save time but may be caught and pay a speeding ticket:

$$\begin{aligned} & \textit{Belief}_3 \\ &= \textit{brf}\{\textit{Belief}_2, \{\textit{aggressiveDriving} \cap \textit{caught} \rightarrow \neg\textit{enjoyRide}, \textit{caught}\}\} \\ &= \textit{Belief}_2 \\ & / \{\{\textit{aggressiveDriving} \rightarrow \textit{enjoyRide}\} \} \end{aligned}$$

- **Belief Revision**

Because the new beliefs lead to an inconsistency, the agent has had to drop his belief in:

aggressive Driving → enjoyRide

- **Generate Options**

Revising desires and intentions: again

$$Desires_3 = options(Belief_2, Intentions_2) = \{ACC, Wait, Press\}$$
$$Intentions_3 = filter(Belief_3, Desires_3, Intentions_2) = \{enjoyRide, SuperCruise, ACC, Wait, Press\}$$

- **Generate Options**

Because it's not longer consistent to drive aggressively (even though it may be preferable to activate SuperCruise), the agent drops that intention and re-adopts SuperCruise (and consequences).

Thank you for your attention!