Belief - Desire - Intention (BDI) Model

BDI Introduction, Applications and Analyses

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1. Introduction
   BDI Scope
2. Implementations
   Why multiple implementations?
3. Applications
4. Case Scenario
   Possible approaches
   BDI Approach
5. Results
6. Comparison
7. Observations
8. Conclusion
BDI is a software programming paradigm used for implementing intelligent agents.

BDI stands for:

- Belief
- Desire
- Intention

The original principles were set by Michael Bratman during the 80s.
BDI as whole can be represented by the following components:

- **Belief** = The knowledge of the world, state of the world.
- **Desire** = The objective to accomplish, desired end state.
- **Intention** = The course of actions currently under execution to achieve the desire of the agent.\(^1\)
- Set of plans supplied at design time.

Reduce action decision time by eliminating inconsistent choices relative to the intention.\(^2\)

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Execution Cycle

Introduction  Implementations  Applications  Case Scenario  Results  Comparison  Observations  Conclusion

Fig. 1 BDI Execution Cycle

\[ G. \text{Jakobson, A. Corp, N. Parameswaran, J. Buford, L. Lewis, R. Pradeep} (2006) \text{Situation-Aware Multi-Agent System for Disaster Relief Operations Management.} \]
"Software agents (in particular, BDI agents) provide the essential components necessary to cope with the real world."

Fig. 2 Graph shows scope of BDI

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Limitations

- Lack of learning competences.

- Lack of explicits architecture for multi-agents behaviour.

- Overthinking in certain scenarios.
Different agent architectures:

- **Procedural Reasoning System (PRS)**
  Developed for embedded applications.

- **distributed Multi-Agent Reasoning System (dMARS)**
  Evolution of PRS including multi-agent behaviour.

- **JACK**
  Build for defence simulation.

- **AgentSpeak(L)**
  Agent-oriented programming language.

- **JASON**
  Development platform for AgentSpeak.
BDI model itself does not specify how to handle each component behaviour.

- PRS uses database for beliefs.
- AgentSpeak agent is a reactive planning system.  
- dMARS plans represents procedural knowledge.
- ...

Overcoming original limitations:

- Agent systems needs to be distributed.
- Adapting to changes from experience.

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BDI agents can be used to solve problems with partial information in a complex and dynamic environment.

For instance:

- Air-traffic control
- Autonomous space-craft control
- Health care services
- Industrial control systems
- Robot soccer

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OASIS (Optimal Aircraft Sequencing using Intelligent Scheduling).


Multiple Agents, each tackling sub-problems. Agents communicate using asynchronous messages.\(^7\)

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\(^7\) M. Ljungberg, A. Lucas (1992) The OASIS air-traffic management system. PRICAI, Seoul, Korea
List of agents:

- SEQUENCER Agent
- AIRCRAFT Agent
- WIND MODEL Agent
- ...

Possible BDI instance in this scenario:

- Belief = Planes position.
- Desire = Decrease speed of aircraft.
- Intention = Adopted plan.

Changes in the environment leads to reassessing intentions.\(^8\)

\(^8\)M. Ljungberg, A.Lucas (1992) The OASIS air-traffic management system. PRICAI, Seoul, Korea
Applying reinforcement learning and BDI model to create a better strategy for Robot Soccer.  

Multi-Agent cooperation overtakes individual optimisation. All the agents pursue a common optimum solution.

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9Guo Qi, Wu Bo-ying (2009) Study and Application of Reinforcement Learning in Cooperative Strategy of the Robot Soccer Based on BDI Model, IJRS Vol. 6 No. 2 pp. 91-96 PRICAI, Seoul, Korea

10http://static.nautil.us (2016)
Possible approaches

▶ Pure reactive
   If something happened, I am going act on it.

▶ Behaviour tress + Fuzzy Logic
   Leaf nodes used as action to change state of the robot.
   Non-leaf node are used to move within the tree.\(^{11}\)

▶ BDI
   Define Belief, Desire and Intention. Provide a plan library.

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Robot soccer control using behaviour trees and fuzzy logic, ICAFS
Architecture of the Agent is Implemented in dMars as a several set of plans:\textsuperscript{12}

- Plan for managing Agent’s role.
- Plan for managing Agent’s responsibility.
- Plan for managing Agent’s strategies.

There are also two intention threads:\textsuperscript{12}

- Intention thread for Agent’s role.
- Intention thread for Agent’s responsibility.

\textsuperscript{12}S. Ch’ng, L. Padgham (1998) From roles to teamwork: A framework and architecture, Applied Artificial Intelligence
Procedure to choose the role of an Agent:\(^{13}\)

1. Update beliefs.
2. Select a role.
3. Become the role.
4. New intention thread.
5. Might discard old responsibilities.

Failing a responsibility cause the role to terminate.

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\(^{13}\)S. Ch’ng, L. Padgham (1998) From roles to teamwork: A framework and architecture, Applied Artificial Intelligence
Example of Corner kick used in the paper.

Fig. 5 Show a pass team strategy, where one by one each player select a role and take position.\(^\text{14}\)

\(^{14}\text{S. Ch’ng, L. Padgham (1998) From roles to teamwork: A framework and architecture, Applied Artificial Intelligence}\)
The article showed that roles can be assigned quickly and dynamically.

It is prone to errors if something happens in between decisions.\textsuperscript{15}

Specifically needs to research more when to drop a plan and move on.

\textsuperscript{15}S. Ch’ng, L. Padgham (1998) From roles to teamwork: A framework and architecture, Applied Artificial Intelligence
Experiments to compare coordinated action selection (BDI), against Reactive actions.

Both executed using simulation and real robots in a Two vs Two scenario:

\[\text{Fig. 6 Scenario used in the experiments}^{16}\]

The experiment simulates two robots while they attack.

Each simulated experiment uses a different configuration for defence:

- Defender and Goalie.
- Midfield defender and defender.

However for real robot experimentation, only Defender/Goalie configuration (Time Constraint).\textsuperscript{17}

\textsuperscript{17}R. Ros, J. L. Arcos, R. L. de Mantaras, M. Veloso (2009) A case-based approach for coordinated action selection in robot soccer IIIA, CSIC
The simulation showed that the robots implementing BDI performed better overall.

The reaction method only outperformed the BDI in Scenario 4.

They noticed that the Reactive approach is faster at attacking the ball. ¹⁸

Fig. 7 The graph shows how commitment to a decision affect the final outcome.¹⁹

Advantages / Disadvantages

Advantages:

▶ Saving computation power, no need to build a new plan every time.

▶ Stay flexible by changing subgoals based on the changes in the environment.

Disadvantages:

▶ Needs to supply plan library at design time.

▶ Some implementations however jump from one plan to another when their Belief changes too often.

▶ A true BDI system that behave like humans is hard to implement.
The challenges encountered during development fall under the BDI scope area:

- The environment is non deterministic.

- Players have to change roles based on environment (Beliefs).

- The changes have to be low in computational power.

- Multi-Agent system.

- Actions can be gathered in plans.
Solid model to implement human-like practical reasoning Agents.

Multi-Agent coordination needs to be part of the system even if it is not specified in the original BDI model.

Still needs more research, probably a perfect system would incorporate a DBI deliberation system and Reactive system in synergy.