

players and NPCs. A successful autonomous agent should also endeavor to collect gold and resources, purchase better equipment, and earn more experience to become a more powerful character.

These goals require the agent to possess reasonably sophisticated inference abilities. It must have a framework to understand the world in which it lives. It must integrate sensory information from the world into this framework. Further, it must be able to determine, based on its understanding framework and sensory information, the reasonable courses of action to survive and succeed in the game environment. Such abilities require a powerful and efficient inference system.

Survival in a real-time hostile world also implies a need for excellent real-time coping skills. Since we wanted the agent to figure out at runtime the strategies for living in the MUD, given some knowledge of the world and a few immutable survival goals, a pre-compiled inference network was not a sufficiently flexible solution. Without substantial limitations on the inference powers of the engine, we worried that inference speed would be inadequate to handle the real-time aspect of the MUD. Moreover, certain aspects of interacting with the environment, such as perceiving the surroundings or carrying out routine actions, did not conceptually belong in an inference mechanism. We thus decided to employ a separate, independent mechanism for coping with real-time world interactions.

These two constraints – of skillful coping with the world on one hand, and of logical inference on the other – suggested a natural division of the agent architecture into two systems, responsible for coping and thinking.

Hybrid architecture

being-in-the-world employs a two-level hybrid architecture: *Descartes*, the reasoning module, which includes the agent's internal state, world understanding, and goal maintenance, and *Heidegger*, the real-time coping module, which tries to satisfy the agent's most immediate goals while dealing with the world in a simple but timely manner. The modules run asynchronously and largely independently of each other. Communication between modules is accomplished through a queue of goals and a shared world ontology.

Descartes

The agent's planning layer is essentially a logic-based truth maintenance system and reasoning engine (Forbus and de Kleer 1993). Rules about the world resemble the following example:

```
(rule ((:TRUE (IS-A ?subtype
                ?superType))
      (:TRUE (INSTANCE-OF ?x
                ?subtype)))
      (rassert! (INSTANCE-OF ?x
                             ?superType)))
```

which, for instance, states that any object that is an instance of a subtype is also an instance of all supertypes. Then, if the agent would come across some item KNIFE123 that was an instance of a knife, and it knew that a knife is a subtype of a weapon, it would infer that KNIFE123 is also an instance of a weapon.

Descartes would then use the continuously updated knowledge of the world (provided by Heidegger) to decompose its high-level goals to a graph of simple, immediate goals. For example, Descartes understands weapons and money – that some weapons are better than others, that it needs gold to acquire them, that other agents have gold, and that the way to get that gold is to kill someone and loot their body. When the 'ACQUIRE-ITEM KNIFE123' goal is activated within Descartes, the system would determine that:

- It needs gold to purchase the knife
- It is poor, so it activates the 'ACQUIRE-GOLD' goal.
- That the 'ACQUIRE-GOLD' goal can be satisfied by killing and looting.
- It knows that street sweepers are weak creatures, so it activates the 'KILL-CREATURE sweeper' goal.

Because Descartes by itself cannot actually *do* anything, it communicates its conclusions to Heidegger, which then tries to meet Descartes' goals. The goals are expressed as concrete actions in the world, such as going somewhere, picking things up, attacking, and so on.

Heidegger

The coping layer is responsible for sensing and affecting the MUD world. It integrates the information from sensory inputs into the knowledge base, and carries out simple actions/goals in the world. It also includes closed-loop reactions triggered when the agent's survival is threatened and immediate action is required.

Heidegger copes with the world in the sense that it knows how to perform concrete actions in the world, and includes built-in reactions to events that cannot wait to be processed by the thinking layer. Thus, the coping layer knows how to get to locations in the MUD, how to pick up objects, or how to attack creatures, and performs appropriate actions per Descartes' request. However, in high-priority situations such as getting attacked, it will deal with the situation directly, ignoring the goals received from the upper layer.