Agent-oriented Computing

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Goal of Today

- What are “Agents” and why are they useful?
- How do they impact on software and service development?

- Three key themes (i.e., three parts of today’s course):
  - Autonomous Agents
  - Multiagent Systems
  - Agent-oriented Software Engineering
Outline of 1st Part:

- What are Autonomous Agents?
  - Objects and Services vs. Agents
  - Definitions
- Agent Architecture
  - Reactive
  - Goal-oriented
  - Utility-oriented
- Agent Systems
- Agent examples
- Agent Applications

Objects and Services: the “Classical Perspective”

- This is what we learn an object is:
  - State (instance or state variables)
  - Methods (operations)
- Methods are requested by other objects
- Similarly for service-oriented programming

```java
Public class MyClassicalObject {
    int var1;
    char var2;
    Object ob3;

    public int firstmethod(int x)
    {
        int results;
        result = someop(x);
        return x;
    }

    Public void secondmethod()
    {
        System.dosomeaction();
        ob3.invokesomemethod();
    }
}
```
Objects and Services: the Real Scenario

- Actually, other than state and methods
  - Internal threads
  - Event-handling
  - Messaging
  - Access to contextual information

```java
public class MyModernObject
    Implements Threads, EventListener{
    int var1;
    char var2;
    Object ob3;

    public int firstmethod(int x)
    {
        int results;
        result = someop(x);
        return x;
    }

    public void secondmethod()
    {
        System.dosomeaction();
        ob3.invokesomemethod();
    }

    run()
    {
        Context lc = Naming.lookup("LocalContext");
        Object cooler = 
    }
}
```

So What?

- Is this still an object?
  - It does much more than an object or a simple service to which to request information
  - It contains much more components and characteristics

- Would you still call a car enriched with a reaction engine, capable of flying, with an automated pilot, still a car. Or would you rather invent another name (e.g., “airplane”) to refer to it?
From Objects and Services to Agents

- The “grown-up” objects and services of modern adaptive software are
  - Not purely functional (they do not simply answer to request of services but rather try to achieve an objective, a goal)
  - Capable of unsolicited execution (due to internal threads)
  - Adaptive (they can dynamically acquire information and tune their behavior accordingly)
  - Situated (access to contextual and environmental information)
  - Social (they interact with each other either via messaging or via mediated interactions via the environment)

- This is very close to the definition of agents...

The Concept of Agency

- From the Webster Dictionary
  1. *how a result is obtained or an end is achieved*; "a means of control"; "an example is the best agency of instruction"; "the true way to success"
  2. *a business that serves other businesses*
  3. *an administrative unit of government*; "the central Intelligence Agency"; "the Census Bureau"; "Office of Management and Budget"; "Tennessee Valley Authority"
  4. *the state of serving as an official and authorized delegate or agent*
  5. *the state of being in action or exerting power*; "the agency of providence"; "she has free agency"

- From the Latin “agentis”: “those who act”
- So, an "agent" is someone who act on behalf of other, with power to act derived from a delegation
Examples of Real-world agents

- Secret Agents
- Travel Agents
- Real Estate Agents
- Sports/Showbiz Agents
- Purchasing Agents

What do these jobs have in common?
- They engage in tasks each with a specific goal (e.g., finding a spy, selling a house, finding a job for soccer player, etc.)
- They are delegated by someone (the government, a house owner, a soccer player)
- They know how to do (have the power and the knowledge to do)

Software Agents

- In general, we can talk of “software agents” when
  - Referring to software that has a “goal” to pursue
  - Acting on our behalf to pursue that goal
  - Having the power and knowledge to pursue this goal in autonomy
- “Agent” is one of the more ubiquitous buzzwords in computer science today.
  - It’s getting used for almost any piece of software
  - In several cases, unappropriately
- In any case, we need some more “technical” characterization and definition
Examples of Software Agents

- Filtering agents (antivirus, anti-spam)
  - They have a goal to achieve → monitoring resources and filter viruses and spams
  - They are fully delegated to act on our behalf → we do not even want to know what and how they are acting → we trust them!
  - They know how to do (have the code to analyze streams, and the knowledge – i.e., the filter rule – to act)

- Shopbots/price comparison agents
  - They have a goal to achieve → find a good with a low price
  - They are fully delegated to act on our behalf → We only want to know the final result
  - They know how to do (have the code to access XML Web resources, and the knowledge to interpret XML files describing goods)

Software Agents: Definition

- A software agent is a component that is
  - **Goal-oriented**: designed and deployed to achieve a specific goal (or to perform a specific task)
  - **Autonomous**: capable of acting in autonomy towards the achievement of its specific goals, without being subject to a globally controlled thread of control
  - **Situated**: it execute in the context of a specific environment (computational or physical), and is able act in that environment by sensing and affecting (via sensors and actuators)

- In addition, it can be
  - **Proactive**: It can act opportunistically and in an unsolicited way towards the achievement of its goals (as opposed to Reactive agents, that acts only on reactions to events)
  - **Social**: Interact with other agents in a multiagent systems.
The Concept of Goal-orientedness

- How is a global application goal achieved?
  - Division of labor (as in object-based and service applications)
    - Functions assigned to different components
    - Coordination is for composing functionalities to lead to global goal
    - As in pipe organizations
  - Division of responsibilities (as in agent-based applications)
    - Sub-goals assigned to different components
    - Coordination is for orchestrating the achievement of a global goal
    - As in modern distributed organizations

The Concept of Autonomy

- Related to “decision making”
  - Centralized decision making, as in process-based and object-based applications
    - Global goal achieved via a global control scheme for the application entities
    - Design by delegation of control
  - Distributed decision making, as in agent-based applications
    - Sub-goals assigned to autonomous agents (integrating execution capabilities, i.e., threads) which try to achieve in autonomy their own goal
    - Design by delegation of responsibility
    - Agents can say “NO!”
The Concept of Situatedness

- We have already discussed that context-awareness is important for adaptivity
  - And it is even more important when
    - Goal-orientedness
    - Distributed decision making
  - Are involved

- Objects are typically not situated: they interact in a world where everything is an object

- Unfortunately, there are also several agent systems that do not take situatedness into the proper account...

- Clearly, autonomy and situatedness make agent adaptive entities, suitable for the dynamics of modern software scenarios!!!
The Concept of Sociality

- Agents are rarely living in an isolated mono-agent world
  - They usually live in a multi-agent world
- Sociality refer to the fact that the typically interactions are more sophisticated than client-server ones
  - Exchange of knowledge
  - Delegation of tasks
  - Open world, competitions in actions, negotiations
- Mediated interactions via common portions of the environment
- Resembling more the interactions occurring in a society of humans...
- Clearly, the capability of acting in a social context is expression of adaptivity, and will make it possible to build, with agents, very adaptive and complex systems, able to deal with openness of the system and (together with situatedness) with environmental dynamic!!!

Classical Objects and Services vs. Agents

- Function-oriented vs. Goal-oriented
- Centralized decision making vs. decentralized (and responsible) decision making
- “all is an object” vs. “agents and environment”
- Objects and Services are purely reactive while agents can be proactive
- Interactions in objects and services systems are merely client-server and devoted to transfer of execution control
- Interactions in agents can be more sophisticated and involve communication and negotiation, as in real-world human societies
- Clearly, it is not always black and white...
Modern Objects and Services vs. Agents

- Modern objects have features that can make objects resemble agents...
  - They can have autonomous threads of execution
  - They can handle events
  - They can dynamically discover partners
  - They can exploit the MW services to sense and effect contextual information

- In effect, several systems for “agent-oriented programming” can be considered simply as advanced tools for object-oriented programming or for more dynamic forms of service-oriented programming
  - Several Java agents are grown-up objects
  - However, it is also possible to conceive very different internal architectures for agents

Agents vs. Intelligent Agents

- The concept of agency we have given is often considered very weak
  - For many persons, agents do not simply have to be goal-oriented, autonomous, situated
  - They have to be “intelligent”

- Traditionally, this means they have to integrate “artificial intelligence” tools
  - Neural networks
  - Logic-based reasoning
  - Conversational capabilities (interact via a conversation language)
  - Etc.

- But what does intelligence really mean?
  - Can we really define intelligence?
  - Or is it in the eyes of the observer?
The Intentional Stance

○ We often speak of programs as if they are intelligent, sentient beings:
  - The compiler can’t find the linker.
  - The database wants the schema to be in a different format.
  - My program doesn’t like that input. It expects the last name first.

○ Treating a program as if it is intelligent is called the intentional stance.
  - It doesn’t matter whether the program really is intelligent; it’s helpful to us as programmers to think as if it is.

○ In agent-based computing
  - Goal-orientation, Autonomy, situatedness
  - Can be conceived as observable expressions of intelligence
  - Even if it is simply a Java program after all...

The Knowledge Level

○ The intentional stance leads us to program agents at the knowledge level (Newell).
  - Reasoning about programs in terms of:
    - Facts and Beliefs (rather than variables and data)
    - Goals and behaviors (rather than functionalities and methods)
    - Desires/needs/wants/preferences

○ This is often referred to as declarative programming.
  - It is a different way of thinking and representing things

○ We can think of this as an abstraction, just like object-oriented programming.
  - Agent-oriented programming
Agent Architectures

○ What types of architectures can we conceive for agent?
  ● Reactive (or tropistic)
  ● Reactive with State (hysteretic)
  ● Goal-oriented
  ● Utility-oriented

Reactive Agents

○ Perceive events
  ● Simple set of rules event → action (i.e., activation of a specific behavior)
  ● Actions are often known as “behaviours”
  ○ Example of a simple “mail agent”:
    ● if send mail then check virus
    ● If new mail then check spam
    ● If spam then send message to friends agents
    ● If new message then get new spam information
  ○ Pros:
    ● simple and efficient
  ○ Cons:
    ● Action depending only on stimuli
    ● Not flexible
    ● Not really autonomous
Reactive Agents

- Sensors
- Current Environment
- Select Actions
- Actuators
- Comms from other agents
- Comms with other agents

Reactive Agents with State

- Internal state (internal knowledge)
- Update of internal state
  - New state = actual perception + old state
  - The update may require
    - Knowledge on how the world evolves – which can also dynamically acquired by the agent
    - Knowledge on how the agent actions influence the world
  - Select action (i.e., behavior) accordingly
- Example
  - A mail agents that keeps track of the users marking some messages as “spams” and take these into account in future actions
- An object is a sort of reactive agents, but
  - It has no rule for action selection
  - It actions are directly commanded by the external
Reactive Agents with State

Goal-oriented agents

- Goal → a desired situation to eventually achieve
- The agent exploits the goal and its knowledge
  - select actions whose effect would be that of approaching the goal
- How can an action be selected?
  - Search in the state space
  - Plannings
  - Heuristics → sub-optimal actions

- Example: an agent to minimize fragmentation in a hard-disk
  - Knapsack problem
  - Do not know the future but know the past
  - Select allocation of new files based on some heuristics
  - An action do not necessarily minimize the current fragmentation
  - Perform de-fragmentation action when the computer is idle
Goal-oriented Agents

[Diagram showing the interaction between sensors, state, environment evolution, actions effect, goals, action choice, current state, environment after actions, and effectors with a mention of communications from other agents]

Utility-oriented Agents

- The Goal is that of maximizing the current utility
  - opportunistic behavior
- Utility
  - A function of some parameter, measuring the state of “goodness” (with respect to the agent) of a situation
  - Often, it measures a trade-off between contrasting objectives
- Example
  - An agent to maximize CPU utilization
  - Always select the ready process
  - The current choice may be sub-optimal with regard to the global execution time of processes
Utility-oriented Agents

Hybrid Architectures

- Mixing utility and goals
  - An agent that has to achieve a goal and, at the same time, has to maximize a specific utility function
    - Trade-off between the two goals, which may be contrasting
  - Often, the various ways to approach a goal can be quantified by a utility function
    - Do the actions that approach the goal with the maximal utility

- Mixing reactive and goal-oriented behavior
  - A long terms goal that include several short term actions on the environment
  - That could lead to sub-optimal choices
Rational Agents

- How do we determine the right thing for an agent to do?
  - If the agent’s internal state can be described at the knowledge level, we can describe the relationship between its knowledge and its goals (or utility function).
- Newell’s Principle of Rationality:
  - If an agent has the knowledge that an action will lead to the accomplishment of one of its goals (or to the maximization of its utility), then it will select that action
  - This clearly applies to human agents too
- Game Theory and Decision Theory is indeed of great importance in modern software development!!!!

Preferences and Utility

- Agents will typically have preferences
  - This is declarative knowledge about the relative value of different states of the world.
  - “I prefer filling disk C: before starting using disk D:”
  - “I prefer to buy on eBay rather than on Amazon”
- Often, the value of an action outcome can be quantified (utility functions can often be derived for goal-oriented agents too)
  - This allows the agent to compare the utility (or expected utility) of different actions.
- A rational agent is one that maximizes expected utility in its actions.
Other Agent Models

- The one presented is the taxonomy of Russell and Norvig.
  - Maja Mataric has provided an interesting alternative taxonomy.
- Other models may be useful for specific applications:
  - Non-rational agents (e.g., probabilistic or "blind" behaviour), useful for searches in large spaces.
  - Ant-like agents (we will analyse them in the following).
  - Specific architectures for specific types of complex robots (e.g., Sony Asimo has a complex multi-layered knowledge-based goal-oriented architecture).
- In any case, the most successful and general-purpose model for goal-oriented agents seems to be the BDI one.

The BDI Model

- BDI is a very successful and general model to "think" at software agents.
  - The agent has:
    - Beliefs: the fact he knows about the world (its knowledge).
    - Desires: the goals the agent has to pursue, what he desires to eventually occur.
    - Intentions: the current plan of action, what he actually intend to do to satisfy its desires.
- BDI agents are usually specified using logic-programming approaches:
  - approaches that rather than executing "instructions" tries to manipulate – according to specific rules – the base of knowledge and the base of possible actions, and evaluates an utility function to select the intentions based on beliefs.
- Of course, BDI agents can be programmed in normal programming languages, but this may be more complicated...
Agent Systems and Languages

- As when developing “normal” software, developing agent software requires specific programming systems
- Either defining a specific “agent-oriented programming language”
  - There are several proposals in that direction
  - However, frankly speaking, no one is really convincing so far, and likely to achieve widespread acceptance and usage
- Or supporting with specific package the development of agent in existing programming languages
  - Logic-based programming languages (e.g., Prolog agents)
  - Object-oriented languages (e.g., Java agents)
- In the case of Java agents
  - Specific classes are provided with which to define agents and their interactions, according to some specific architectural model
- The case of Multiagent Systems, will in addition require proper Agent-oriented Middleware
  - As we will see, these do not differ much form traditional service-oriented middleware

Agent Examples: The Aglet approach

- Originally produced by IBM
  - Then become open source (we at DII-UNIMORE have been managing it for a while),
- Reactive Agents with State
  - Specifically oriented to network management
  - Perceive network and file systems environment
  - React upon specific events (no specific actions selection)
  - Can autonomously move from node to node (agent mobility)
  - Can interact via message-passing or indirectly via modification of the context of a node
**Aglets: Code Example**

```java
import aglet.*;

public class DispatchingExample extends Aglet {
    private boolean _theRemote = false;

    public void onMessage(Message msg) { // react when a message arrives from an aglet
        System.out.println(who() + "'onDispatching()' is starting...");
        pause();
    }

    public void onArrival() { // react when arriving on a node
        _theRemote = true;
        System.out.println(who() + "'onArrival()' is finishing.");
    }

    // main body of the aglet
    public void run() {
        if (!_theRemote) { System.out.println(who() + "'run()' is starting...");
            // access the local AgletContext to get the URL of the node
            String host = getAgletContext().getHostingURL().toString();
            URL destination = new URL((String)getAgletContext().getProperty("location", host));

            // ask the local AgletContext (which also act as naming service) for another Aglet
            Aglet ag = getAgletContext().getProxy("myfriend");
            Ag.sendMessage("hello how are you?");
            ...}
```

**Agent Examples: the JADE Approach**

- **Goal-oriented type**
  - An agent has a set of behaviors ("actions") that code a sub-task of the agent similar to objects methods
  - And a state, which represents its current knowledge of the world
  - The goal is not "explicit"
  - The agent can be multithreaded
  - Behaviors can be dynamically added on need

- **An agent start with a “setup” behavior that may activate other behaviors**
  - One behavior, when activated, executes to completion and can activate other behaviors
  - Depending on the actual knowledge, and in such a way that the goal may be effectively approach by properly composing the behaviors

- **Agents can interact with each other**
  - In the forms of "Agent Communication Languages", sort of messages exchanges between agents
  - That can influence their knowledge of the world and their behaviors

- **No explicit representation of the environment!!!**
JADE: Code Example

```java
public class SearchAgent extends Agent {
    const int temp_voluta = 23.4; // desire
    int temp_attuale; // beliefs

    protected void setup() {
        System.out.println("Hello. I am " + this.getLocalName() + ".");
        this.searchAgents();
    }

    // another behavior
    private void searchAgents() {
        DFAgentDescription dfd = new DFAgentDescription();
        SearchConstraints c = new SearchConstraints();
        Agent ag = DFServiceCommunicator.Discover("FriendAgent");
        if (ag != null)
            this.searchanother();
        else
            ACLMessage msg = new ACLMessage("Ciao Ciao")
                ag.sendACLMessage(msg);
    }

    // another behavior
    private void searchanother() {
        ...
    }
}
```

Building Agents with Objects

- In theory, we could also exploit a raw object-system to build agents
  - i.e., to build grown-up objects without making use of special JADE or AGLETS classes
  - So as to make them sort of software agents
- This is of course more difficult
  - BUT OUTLINES AN IMPORTANT POINT
- The concept of “agency” is a concept
  - Whenever we have something that is autonomous, situated, goal-oriented
  - We could call it an agent!!!
- Agents are not a language or a system
- They are a new way of thinking software!!!
Agent Applications (1)

- Monitoring and autonomous maintenance operations
  - Anti-spammers and anti-viruses
  - Scheduler for resources
  - Personal digital assistance (e.g. Microsoft agents)

- Control of physical processes
  - Control the functioning of specific production machines
  - Access the sensors of the machine
  - Interfaces with the actuators of the machine
  - Action selection as a “rational” – rather than mechanical or electrical – feedback control loop

- Videogaming
  - Aren’t the characters of modern strategy games software agents after all??

Agent Applications (2)

- Autonomous unmanned vehicles
  - Automatic pilots
  - Self-driving cars
  - Robots
  - MARS Robots

- The specific case of self-driving cars
  - Have the goal of reaching a place (the desire)
  - Have the knowledge about streets (the beliefs)
  - Sense the streets and the traffic conditions
  - Act on brakes, fuel, and directions, to approach the goal
  - At the same time, it has to minimize the danger (utility function)
  - The actual actions (intentions) must be dynamically decided based on current environmental conditions
Agent Applications: However…

- The most interesting applications of autonomous agents are those in which multiple agents interact and concur in a system...
  - Multiagent Systems
  - With specific additional problems to be faced!