University of São Paulo

Polytechnic School of Engineering

Department of Electronic Systems

Handouts of slides of class T4 – Modelling Cognition

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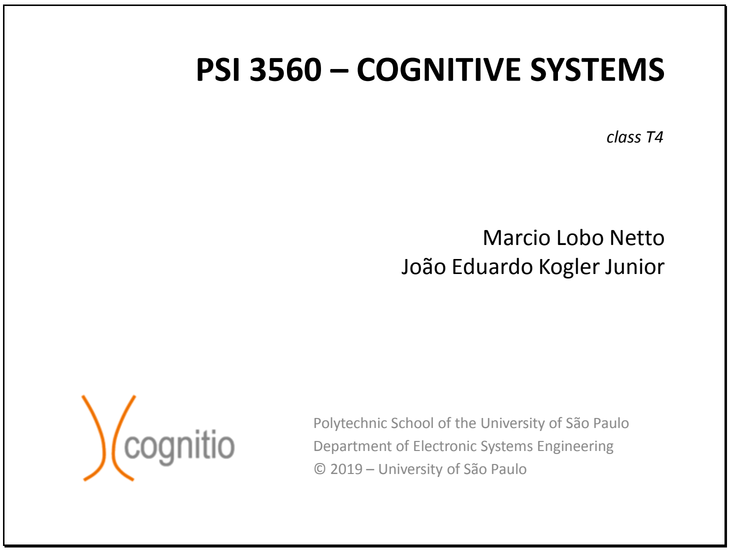
During the COVID-19 pandemic, with remote classrooms, I am providing this text to compensate the lack of face-to-face contact that we are experiencing. I expect that you read this material and prepare for the remote discussion session, on April 7, via teleconference. Enjoy it and keep yourself safe and healthy.

Slide 2

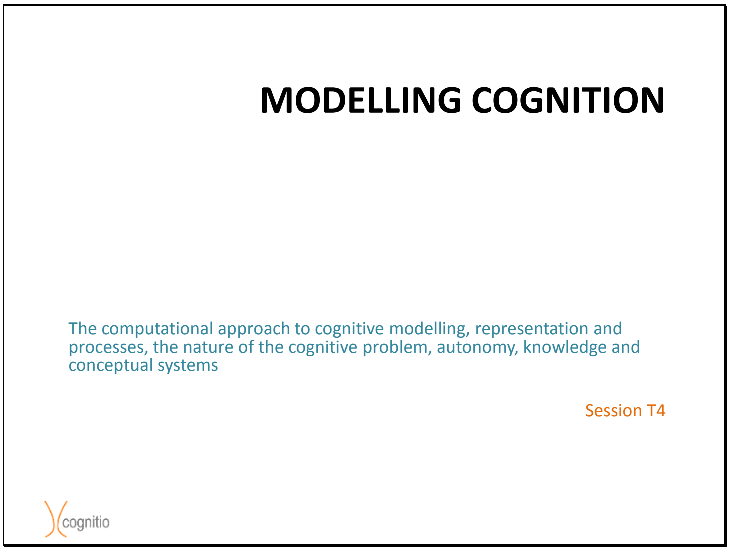


This course targets to the design of cognitive systems. Here, at the engineering school, we are interested in designing devices, artifacts and systems. In our days, there is a growing interest on products supporting high-level interaction capability. This requires machines that deal with persons using natural human communication languages, able to mimic people in situations that require human reasoning accounts for decision-making and similar behavioral control.

Right now, during the isolation regime with social distancing imposed by sanitary protocols, we can identify several benefits in the adoption of the so-called intelligent systems and robotics. In situations like this, robots can go where people would be subjected to unacceptable risks. The employment of ordinary automation requires a formal structuring of tasks and operational environments attained only by industry and systematic services, like postal mail, logistics and similar. On the other hand, the operational conditions inside human environments can involve children, people with special needs, distracted people, and demand the abstraction level of human communication and interaction. This poses requirements that are far from usual for traditional automation design, and characterizes the domain of the so-called smart environments with intelligent objects.

As we have been discussing since our first classes, this application domain requirements are met by a kind of system purportedly considered as cognitive. Nevertheless, *cognition* and *cognitive systems* are terms that deserve very careful explanations, and we have been doing it. As a matter of fact, we'll get into this routinely during the rest of the semester.

Slide 3



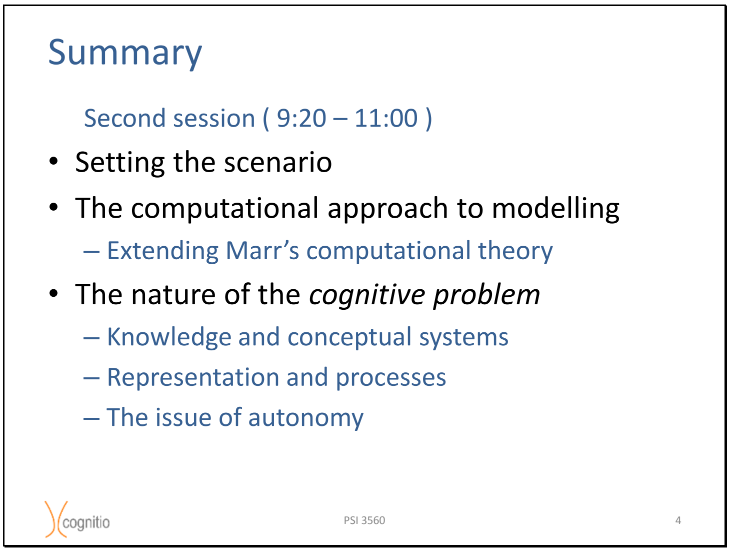
This is the second topic of the syllabus, in which we will examine how to model cognition. Remember that the course has two main parts, part F – the foundations, and part T – the techniques. On part T, we follow exploring the concepts of cognition and cognitive systems under the point of view of engineering – i.e. how to design cognitive systems. On the F part, we follow studying the cognitive systems under scientific and philosophical approaches, in order to set foundations for the technological part.

The first topic of the T part, treated on class T1, discussed the concept of cognitive system and the nature of cognition from a technological standpoint, considering what does really mean to design a cognitive system. This led us to propose a working definition of cognition, suitable to our design needs.

Then, on class F2, employing a philosophical inquiry, we started with the commonsense view of cognition, which led us to the idea that cognition is part of which is called the language of thought.

Now, we can use this view and apply it to our working definition of cognition, and see how this can help us to design cognitive systems. To do this we need to build models for cognitive systems. Therefore, we now discuss how to model cognitive systems, by setting a methodology to produce viable approaches to this question. We will call it the computational approach to modelling cognitive systems.

Slide 4



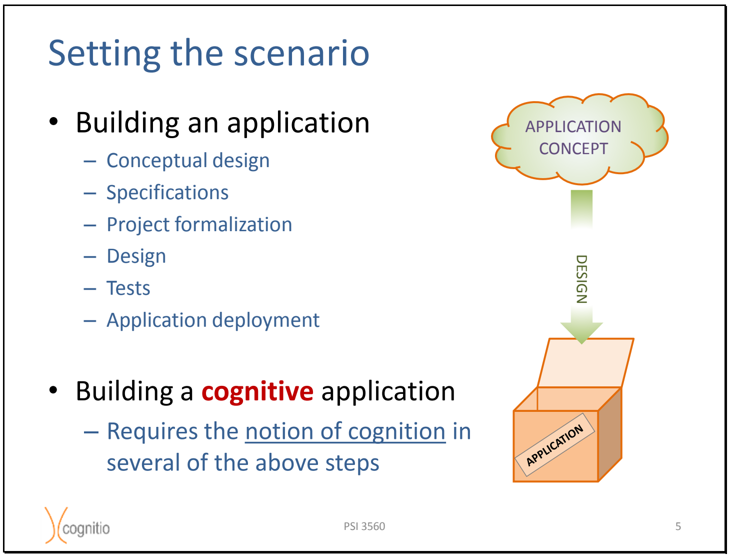
Class T4 is the second session of this week that started with class F4. However, T4 and F4 are conceptually independent. The points addressed on class F4 will affect the technical part in the long term, not at this moment, so, we can proceed without referring to F4 topics by now. You can chose to start with T4 or F4 in any order, if you want, without prejudice to understanding.

In this T4 session about modelling cognition, we will start setting the scenario for this modelling process, by checking where we are now and to which direction we should go. We will first review the main objective of this technical part T, which is to design a cognitive system. Then we will recall the need of the working definition of cognition and go into a more detailed explanation of that definition and its consequences.

In the following step, we will discuss the computational approach to modelling, which means, how to treat a problem such as ours, of cognitive systems design. To carry on the problem-solving methodology of computer science, one should decompose the problem into aspects that evoke particular ways of analysis, namely: (i) a theoretical elaboration of the problem, (ii) a choice for data representation and algorithmic approach, and (iii) the practical / physical means of implementation. This will lead us to David Marr's computational theory of perception, which we will extend to study cognition.

Finally, we will get into the characterization of our problem's domain: how to represent its information data and the processes that manipulate it, paving the road to next classes, which will take on A.I and machine learning.

Slide 5



As we have emphasized lately, our aim is to design cognitive systems. The standard approach to design, as treated on the previous classes, is to follow a structured sequence of technical steps that takes us from the conceptual idea of the product to be developed, to its deployment.

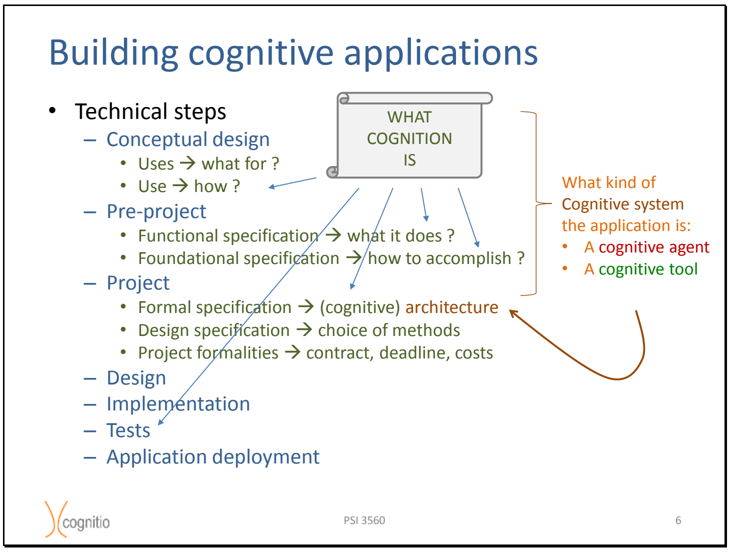
The design process initiates with the analysis of the application concept, identifying its purposes and features, in order to provide general specifications that will serve as the project's guidelines. With these in hands, one can proceed to the formalization of the project, finishing with the formal document containing an agreement of intentions, needs, deadlines, provided services, estimated costs, remuneration and fees.

The next steps, strictly technical ones, consist in the design by its very nature, which comprehends the choices of system architecture, components, design methods, and advance to the elaboration of calculations, technical specifications, and project building, ending with the testing phase.

Finally, the project deployment, finishes with the prototype presentation, assessment, approval (if ok), and delivery.

This is usually valid for the majority of projects, and comes across exceptions only on particularly complex applications. In our case, being it a standard or complex one, what is critically crucial is the understanding of the role of cognition on the application concept, and how it affects the design process.

Slide 6



The concept of cognition, as already discussed, influences design aspects related to the uses of the application. Put in other words, cognition, which is a sophisticated asset, plays its role by making the application viable. If cognition is not relevant for the viability of an application, you should not consider its use in the case.

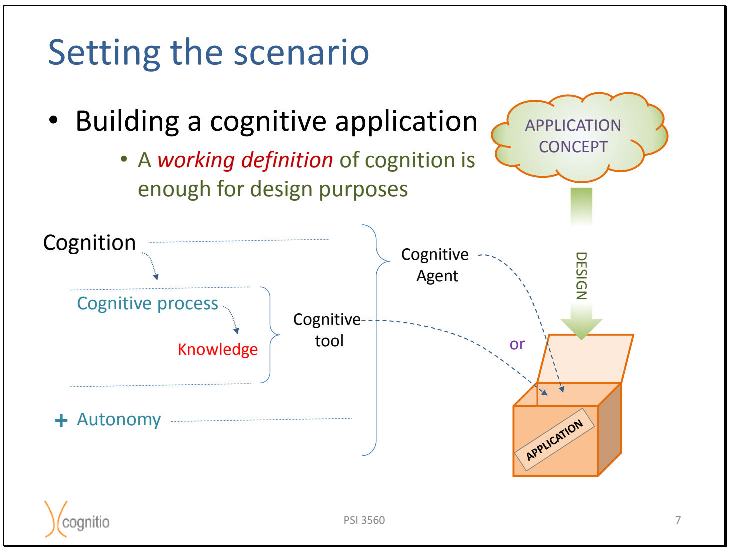
Therefore, once decided that cognition makes difference for the application, one should then identify what type of cognitive system it is: an agent or a tool. All these aspects comprise the conceptual design of the application. On the next steps of design, they will determine the functional and the foundational specifications of the project, which respectively dictate the system's architecture, and the choice of design and implementation methods. Finally, they will settle the testing procedures of the prototype.

As an exercise, you should try the following:

- Pick an idea of application coming up to your mind, which you'd like to develop
  - What does this application do?
  - Is cognition required for the application to provide such functionality?
    - If yes, tell why and then go to the next page.
    - If not, tell why and think of another application.

Write about what you have tried in the example above (at least two cases, one *yes* and one *no*).

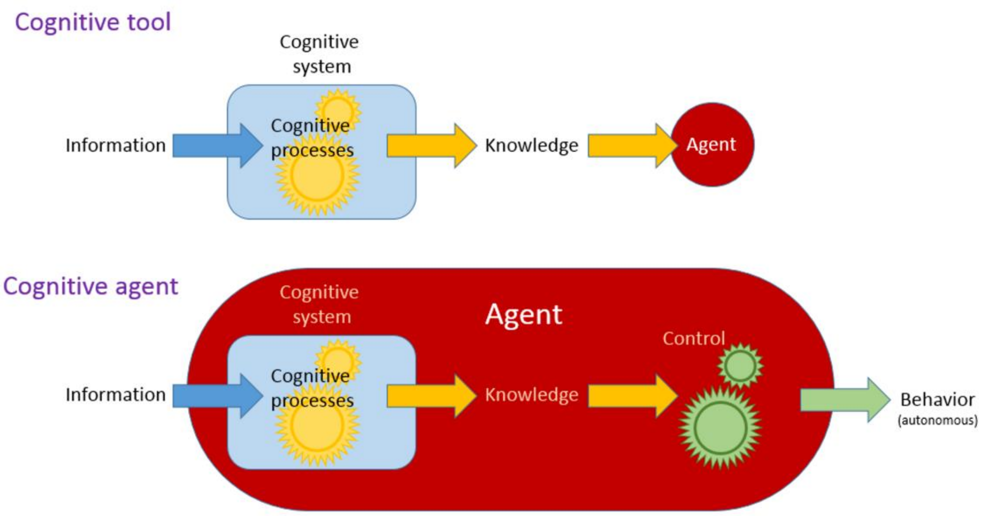
Slide 7



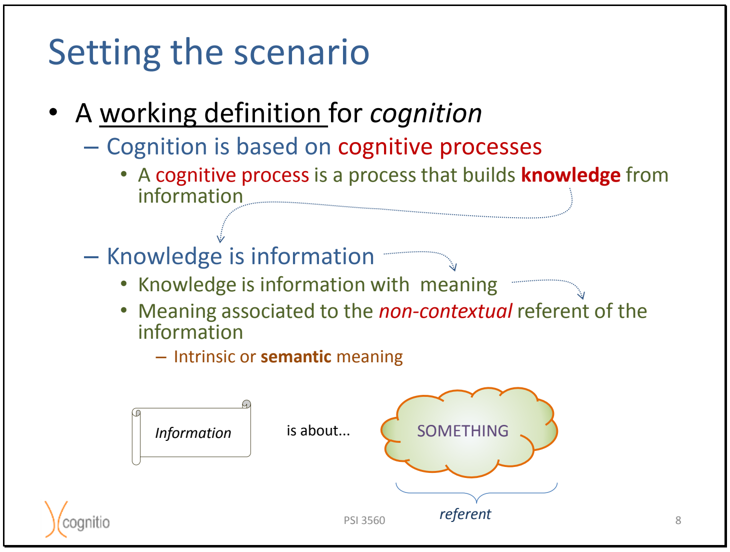
Now, consider that you decided that your project is of a cognitive application. Therefore, what will go inside that box will be a cognitive system.

You must then identify what kind of cognitive system it is: a cognitive agent or a cognitive tool.

- Cognitive system → is a system of cognitive processes.
  - Cognitive process → is a <u>process</u> that builds knowledge from information
  - Two types of cognitive systems:
    - Cognitive tool → provides the knowledge it has built for an <u>external</u> agent to use
    - Cognitive agent → builds its own knowledge required to control its <u>own</u> behavior



Slide 8

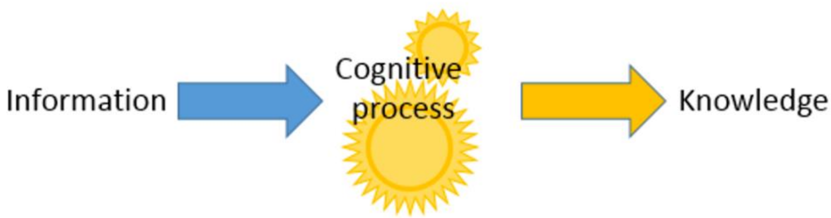


In order to decide if your application is a cognitive system, you must verify if cognition is relevant to make your application viable. In other words, if it is necessary for your application. Hence, you must understand precisely what cognition is so you can identify its features in the application expected functionality. However, currently the conception of cognition is still controversial, thus one cannot state precisely in a definitive manner what cognition is. For this reason, we have to adopt a working definition of cognition, i.e., one such that is enough to our purposes, without being affected by the contentious divergences of points of view.

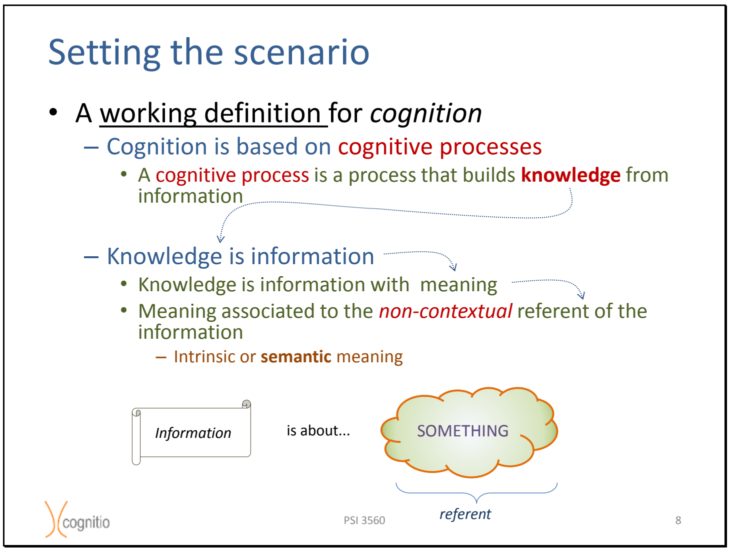
Our strategy to keep away from this quarrel is to base the conceptual view of a cognitive system not in cognition itself, which is the term under dispute, but on a concept less difficult to define: *the cognitive process*.

The word process denotes some kind of transformational procedure: is a series of actions upon something that changes it somehow, or that results in something else.

A cognitive process, as we said before, results in knowledge. It is a process that acts upon some pieces of information and extracts or builds knowledge from all this information.



Slide 8 – cont.



Ergo, knowledge is something that comes from information, or has the nature of information plus something else. Moreover, the cognitive process produces knowledge from information. Therefore, to understand the cognitive process, we must investigate this relation between information and knowledge. Again, we are in serious problem: there is no precise and definitive definition of information, and of knowledge !

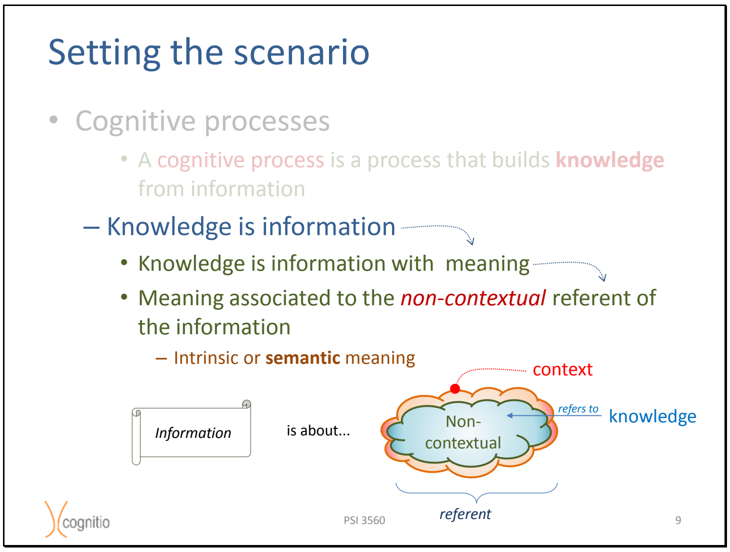
Now, our strategy to circumvent this is to consider information as a primitive concept, i.e. we don't define it and take our intuitive common sense about it as starting point, in the same manner that in Euclid's geometry the concepts of point, line and plane were not given. With this, rests to us to define knowledge. [1]

Knowledge is information too, but of a special kind: it presents meaning associated with only the non-contextual referent of the information. This is called semantic meaning, in contraposition to the pragmatic meaning, which is contextual. To understand this definition, however, it is necessary to clarify several items: what is referent, context, and non-contextual referent.

Information is about *something*, it refers to something. We call referent as being this "*something*", i.e. the entity to which the information refers. The referent can be an object, several objects, objects and their relationships, can be situations involving some objects, etc.

[1] Our approach to this will be very peculiar, however: for the sake of didactics, we will use non-standard concepts, which nevertheless are not in discordance with the usual ones. This conceptualization can be seen as an adaptation of a mentalist theory of meaning.

Slide 9

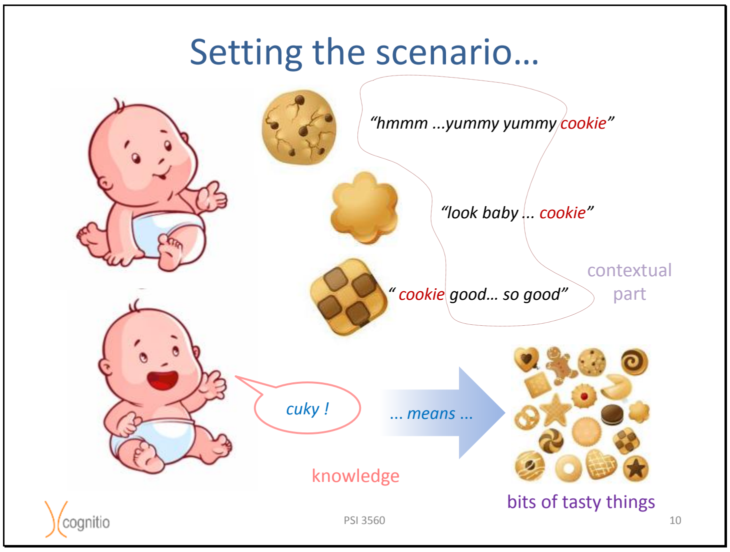


Suppose the following example: a little child is at the park and sees for the first time in the life a duck in the lake. It takes a while to understand that the duck is an animal. The child must identify several features that are characteristic with her previous experience with animals, as: it moves, it has eyes and seems to be looking, it emits sounds, etc. The child is receiving through her senses information about the duck, together with information about what surrounds the duck. These surroundings help her to characterize the duck as an animal. The lake water on which it swims, the things at which the duck stares, the pieces of food the duck eats, and so on. All these are included in the referent of the information about what is a duck. However, except for the duck itself, everything else in the referent just surround the duck and constitute what we call its context, i.e., the contextual part of the referent. The duck itself is the non-contextual part of the referent, and the information referring strictly to the duck (the duck properties: it eats, swims, quacks, etc.) will produce the non-contextual information, which meaning will constitute the knowledge about the duck. Summarizing:

- Information referent is to what a given piece of information refers.
- Knowledge is information too. Thus, knowledge has a referent, which is non-contextual. Knowledge is a special kind of information that must not change with context changes.
- Context is the part of the information referent that helps the understanding of the meaning of the knowledge referent, which is surrounded by the context.
- The knowledge referent is the non-contextual part of the given information referent.
- Knowledge is information which meaning is only about the non-contextual referent.

If the context changes, the knowledge about the entity surrounded by the context does not change. The context just helps the understanding of the meaning involved in the knowledge.

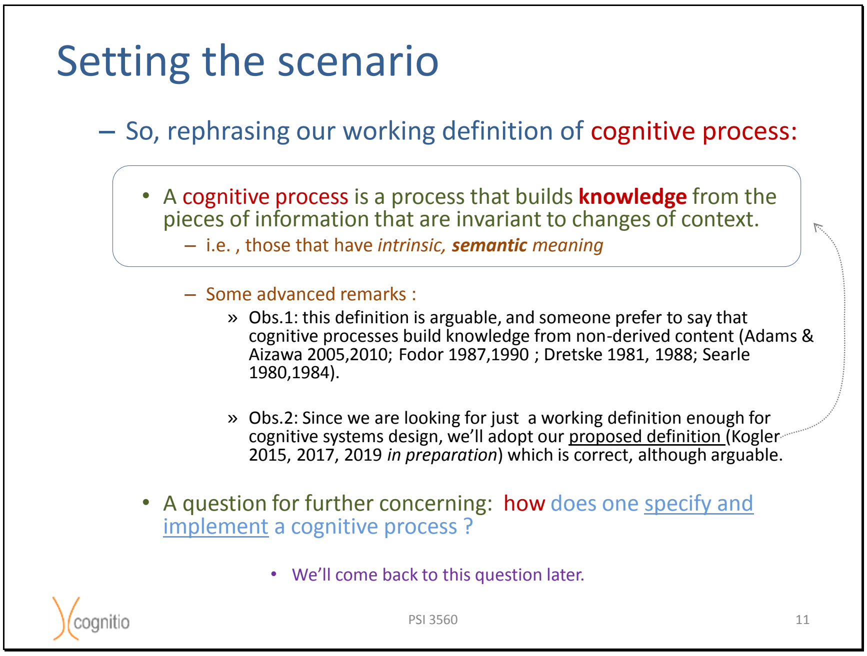
Slide 10



Consider this other example: a cookie is given to a little baby. His mother says something to stimulate him to eat the cookie. The baby finds the cookie very tasty, feels how it smells, its texture, learns its flavor, etc. On another day, a slightly different kind of cookie is given to the baby, and his mother says something slightly different about it, but uses the word cookie again. This repeats many times, with different cookies, sometimes with the same cookies, and so on. While all this happen, the baby is experiencing several little pieces of meal that may change in shape, flavor and other aspects, but always hearing something that includes the word cookie. So, he is building the knowledge about the concept of cookie, referred to the heard word "cookie" that is always present in all situations, despite the fact that several things change (the characteristics of the cookie, what his mother says besides the word "cookie", the environment, how the mother is dressed and how she makes her presence, etc.). All these items that change are contextual. The word "cookie" and the experience of what constitutes a cookie are the non-contextual information that will make the knowledge about cookie. Consequently, when the baby wants a cookie he will utter something that resembles the word "cookie". He now knows how to ask for a cookie, because he generalized over the contexts, retaining the invariant part that is the non-contextual one. Notice that the concept of cookie as presented is something that abstracts all the non-particular aspects of each situation when a cookie is present, retaining only that part of the experience that is regularly present, given some criterion of similarity.

Exercise: give your own example of knowledge construction by generalizing information over contexts, as it was done in the two above cases ("the duck" and "the cookie"), identifying what is contextual and what is not.

Slide 11



- Before following, read again the summary of ideas on page 10.

Remember that our central definition is that of cognitive process. At this point, we are able to rephrase our definition of cognitive process in a more precise fashion:

- A cognitive process is a process that builds knowledge from pieces of information that are ***invariant*** to changes of context.

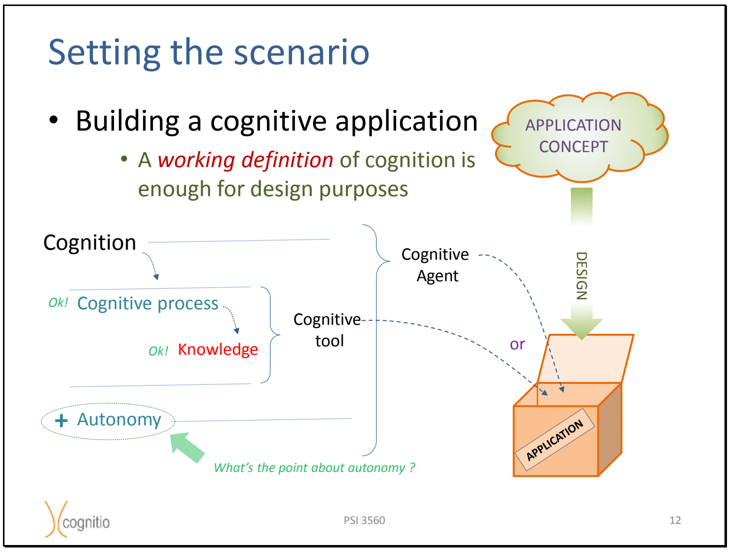
Said in another way,

- a cognitive process receives information as input, containing:
  - parts specifically linked to the context (the lake where the duck is, the food it is eating, the shape of the cookie) and
  - parts applicable to other contexts without changing meaning (the duck will be what it is, regardless of the context; the word cookie will denote a cookie, no matter its shape).
- Then, the cognitive process will preserve those parts that don't change with changes of context, and build knowledge from it, as output.

A further question is how the cognitive process do all these: (i) how it separates the contextual and the non-contextual pieces of information, and (ii) how the knowledge is build, i.e. precisely what means "to build" knowledge, if there is something else besides (i).

Observation: you can skip those advanced remarks in the slide.

Slide 12



Coming back to the slide number 7, where we were talking about the concept of a cognitive system and in what followed, we reduced it to a system of cognitive processes, leaving aside the very idea of cognition. Then, we proposed two types of cognitive systems, namely the cognitive tool and the cognitive agent. Notice (see the slide above) that both types are made of cognitive processes; hence, they build knowledge from given information. So, keep this in mind when you ask yourself if some application you're considering is or isn't a cognitive application.

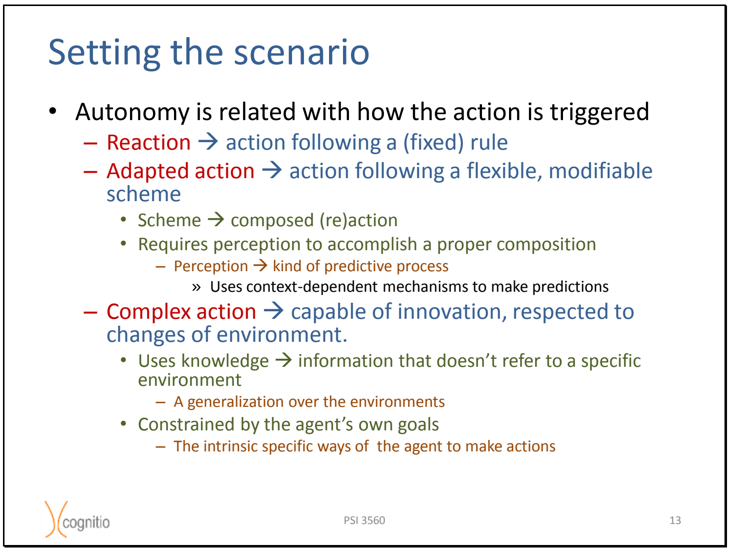
- If it receives or gathers information from its operational domain and builds knowledge taken from this information, then it is a cognitive application.

Just a remark: if the application receives the knowledge ready to use from an external source, then it is not qualified to be a cognitive one. It is just a knowledge-based application. We will get into this further, in future classes.

Recall now page 7 again, and consider the additional picture at the bottom of that page, comparing a cognitive tool with a cognitive agent. In the latter, we have the cognitive processes embedded inside an agent, and this means that the agent builds its own knowledge base required for controlling its action. The idea is that such agent is capable of discovering what else it needs to perform its behavior, when its behavioral control built-in strategies are not able to cope with unpredictable changes on the agent's operational environment. This capability is what we call cognition. Then we can state the

Working definition of cognition: cognition is a system of cognitive processes organized to improve the autonomy of an agent.

Slide 13

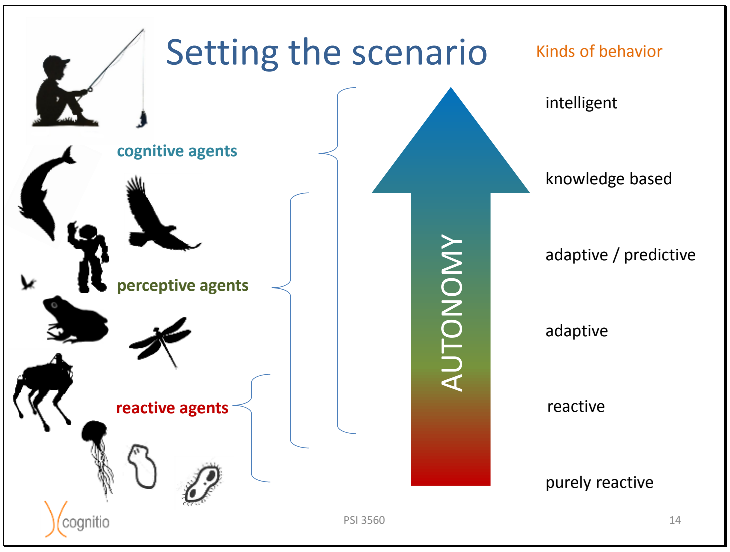


The working definition of cognition implies a related agent. Cognition is a strategy for improving the agent's autonomy. An agent that employs cognition to control its behavior is called a cognitive agent.

Generally, an agent is an entity capable of performing actions controlled by itself. The strategy used to control the agent's actions characterizes what kind of agent it is:

- The reactive agent just reacts to environmental inputs following pre-established fixed rules. Its behavior is called reactive behavior.
- The adaptive agent is a bit more flexible, because it can adapt these rules when occurs environmental changes not covered by the original rules. This is limited, however, by the extent of adaptations it can make to these rules. This behavior is called adaptive behavior.
- More elaborated strategies employ estimates of the environmental changes in response to the agent's own behavior, which is called a perceptual agent, given that those estimates are produced by its sensorial perception. This kind of adaptive strategy is called predictive behavior.
- If the agent is capable of learning from environmental changes and build knowledge to produce suitable strategies for action, then we have the cognitive agent. Its behavior is called knowledge-based behavior.
- Some situations do not lead to clear-cut strategies following from knowledge about the environment. Agents capable of producing innovative approaches, emergent from its knowledge and experience are the so-called intelligent agents. This behavior, called intelligent behavior, leads to the execution of complex actions.

Slide 14

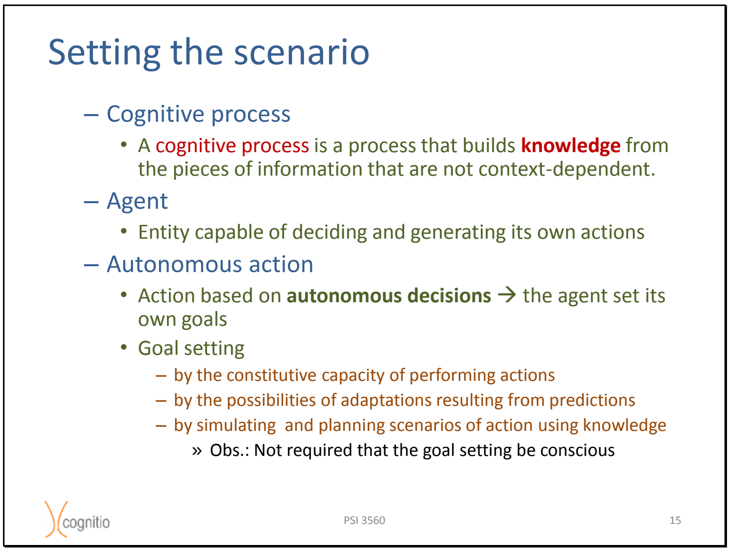


From one agent category to the other, the success facing unexpected environmental changes depends on the employed control strategy. Purely reactive behavior pose great limitations to the agent's chances of success. As the capacity for adaptation of the behavioral control rules improves, the chances of survival increase. The critical improvement is achieved when adaptations follow the dynamics of the environmental changes. A first progress comes with the capacity of predicting changes in the environment resulting of the agent's own actions. This kind of adaptation is clearly dependent on context, provided by the relations between the agent and its surroundings. In this case, sensorial perception is the way to produce the estimates of contextual changes. To improve beyond this point, estimation must go beyond contextual situations, valid only for a limited time interval. The agent should be able to make long-term predictions, which require addressing the causal mechanisms of the changes. This is achieved by detecting correlations among non-contextual aspects of the interaction of agent and environment, which leads to the construction of knowledge. This capability grants the agent a remarkable chance of survival and enables it to cope with a broader range of environments.

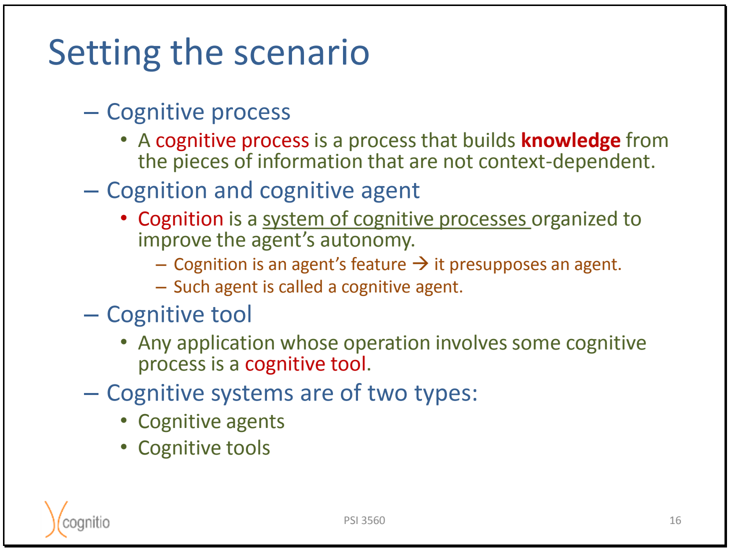
In all these scenarios, one can appreciate an improvement of the autonomy of the agent, translated by its capacity of depending more on its own resources than in favorable properties of the environment. In nature, the evolution of species is the way to improve strategies for fitness to changing environments, increasing agent's ability for autonomous actions.

The strategies for achieving autonomous action are also useful for the design of artificial agents. The use of knowledge about the operational domain grants more autonomy to the agent. If the agent is able to acquire by itself this knowledge, then we have the so-called cognitive agents.

Slide 15



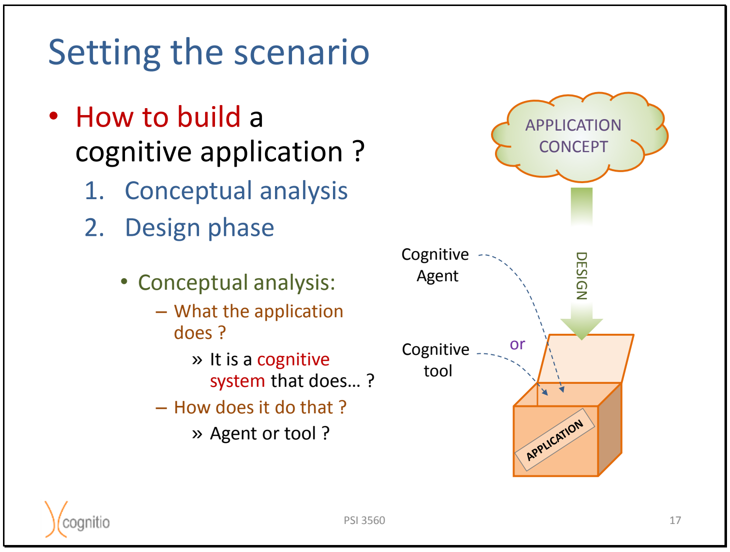
Slide 16



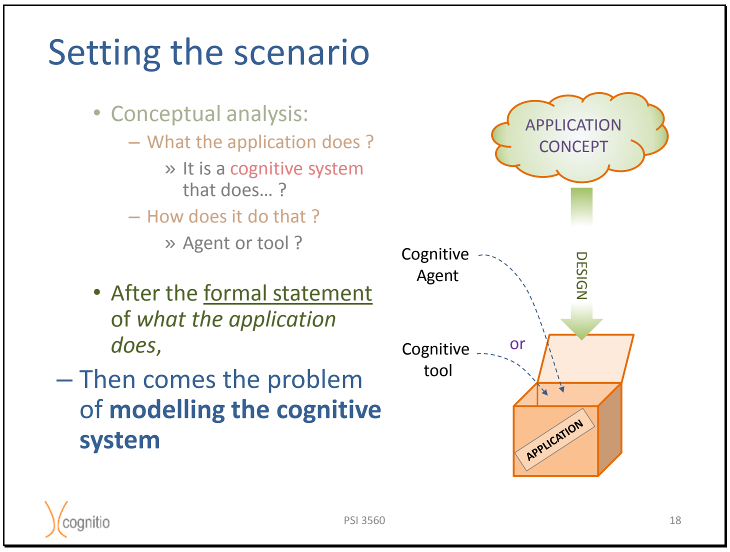
Before going to the next section, we wrap-up all we have until now in this two slides, so not getting lost with all the concepts we have just tackled. After you read these slides, I will just add some extra words about autonomy (think about them):

- Autonomy here refers to the agent's ability of making autonomous decisions about its subsequent behavior. There are other kinds of autonomy, like energetic autonomy, that are not included in this case.
- The resources required for decision-making are information, discernment and intention.
- Information comes with knowledge and sensed data. Discernment involves discrimination, understanding and judgement. Intention translates into goal setting.

Slide 17



Slide 18



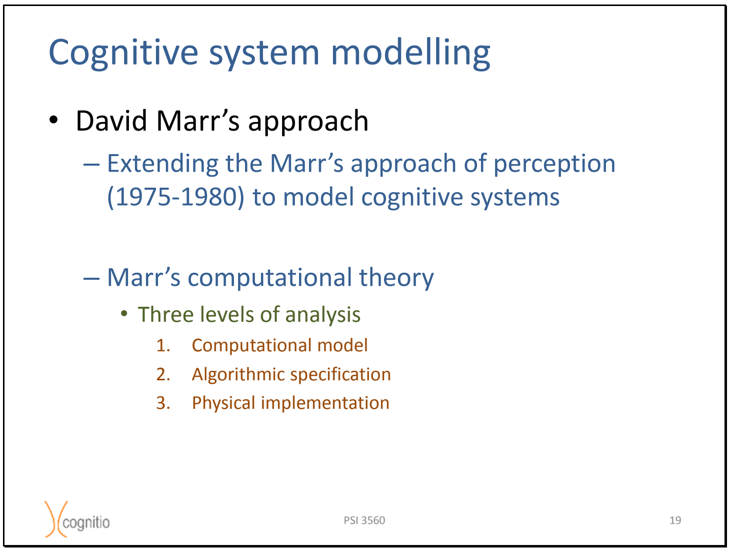
To finish this scenario setting for the next section, let us review our motivation and understand where we are going. Our intention is to understand the design of cognitive systems. For this, we have set the terminology and made a descriptive analysis of a cognitive application conception. We found that:

(i) it is necessary to check if the application is a truly cognitive one, by determining if it has to build knowledge out of information taken from the application domain and,

(ii) Identify if the application is a cognitive agent or a cognitive tool, regarding if is the application that decides and makes the actions based on knowledge, or if a user does this.

With all this, we finish the conceptual analysis and enter into the design phase discussions.

Slide 19



Now that you know that your application is a cognitive system, because you know what it does, and know that building information is essential for its functioning, we reach the question of how to make a cognitive application, be it an agent or a tool. To answer this question we need to know the structure and functional organization of a cognitive application: we must know how to model cognitive systems.

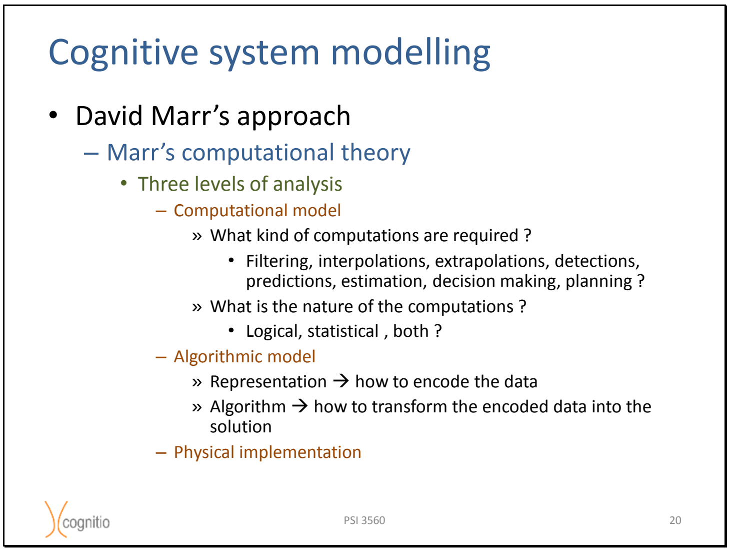
To do this modelling, we will adopt and extend to cognitive systems the famous approach proposed by David Marr about forty years ago, to study primarily the visual perception, but with the intention to apply it to understand the brain functioning, cognition and intelligence. Although Marr was a member of the community that founded and developed the so-called computationalist school of cognitive science, his approach is neutral with the other schools. Nevertheless, radical antagonists strive to challenge this neutrality, but I will leave this discussion to the foundational part of our course on cognitive systems.

Marr’s approach is the computational theory of perception. I will extend it to a computational approach to cognitive systems, including here cognition, perception and all the related functionalities and phenomena. One can take it as a methodology for modelling complex systems that are physically realizable. Based on Marr’s ideas, we can proceed through three levels of analysis of a system that deals with information:

1. The computational model,
2. The algorithmic specification and,
3. The physical implementation description.

The first level is explanatory, the second is a justified specification and the third is descriptive.

Slide 20

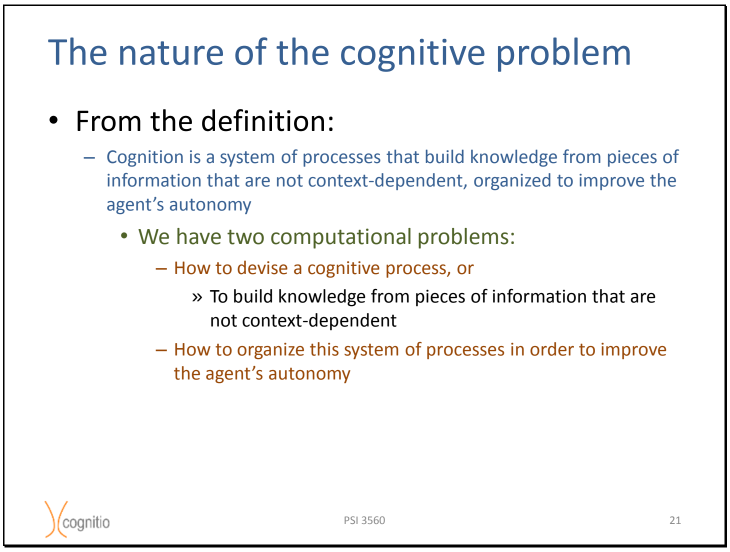


Suppose you want to model some complex system that deals with information, like in our case a cognitive system. To deal with information means to transform and use information. Marr's approach is to consider it a system that is solving a problem that involves these information-dealing processes. His approach was methodological, taking three steps:

1. Build a computational model – this model should express the nature of the information-dealing processes involved, called by him computations. Not computations because they could be done by computers, but because they are processes carried on information. In the slide above, there is a list of such kind of process. In this modelling step, one must identify the inferential nature of these computations: are they logical, statistical, analytic, synthetic or mixed?
2. Specify the algorithmic model – which involves the specification of the representational scheme and of the algorithm. The representation means how the cognitive system organizes and encodes the data containing the information. The algorithm is the description of the processes that transform the information using the specified representation scheme. The algorithmic modelling starts with the computational model and proposes a suitable way of realizing it in terms of operations on data, in terms of viability and performance.
3. Describe the physical implementation – this step can be applied to any kind of physical constitution of the cognitive system, be it natural (biological) or artificial. It provides a description of the physical structures and physical processes that constitute the cognitive system, that physically realize the algorithmic model.

Next, we will discuss these levels in more detail.

Slide 21



To apply Marr's approach for modelling cognition, we start with our working definition of cognition and identify its intrinsic computational problem.

The working definition states:

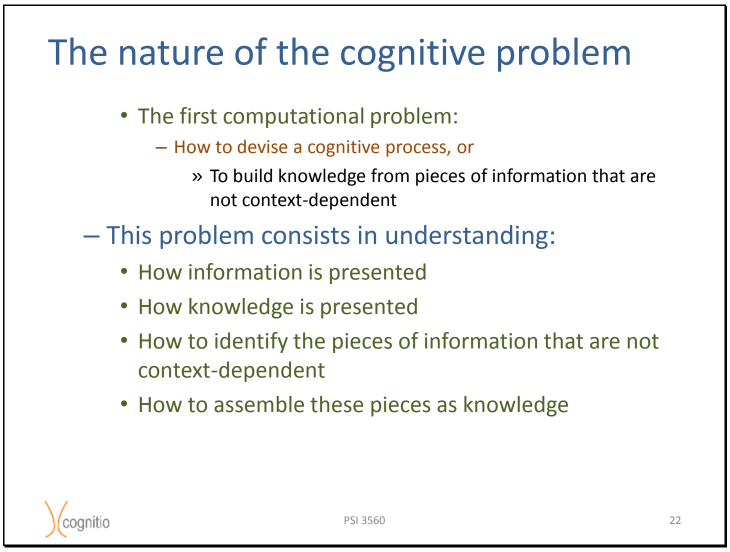
Cognition is a system of processes that build knowledge from pieces of information that are invariant to changes of context, organized to improve the agent's autonomy.

There are two parts in this definition, indicated above in distinct colors. Each part of that statement poses a different computational problem, so we have two problems:

1. The cognitive process problem – or, how the cognitive process perform their action, i.e. how they build knowledge from the pieces of information invariant to context changes.
2. The cognitive agent problem – or, how to organize the system of processes in order to improve the agent's autonomy.

Observation – I have changed the term "not context-dependent", as it was in the 2019 edition of this course, by "invariant to changes of context". In fact, the relevant aspect when considering information as knowledge is not its dependence to some context, but not to change (being invariant) when the surrounding context changes. Recall the examples of the duck in the lake and of the cookie. This will affect all the slides that follows.

Slide 22

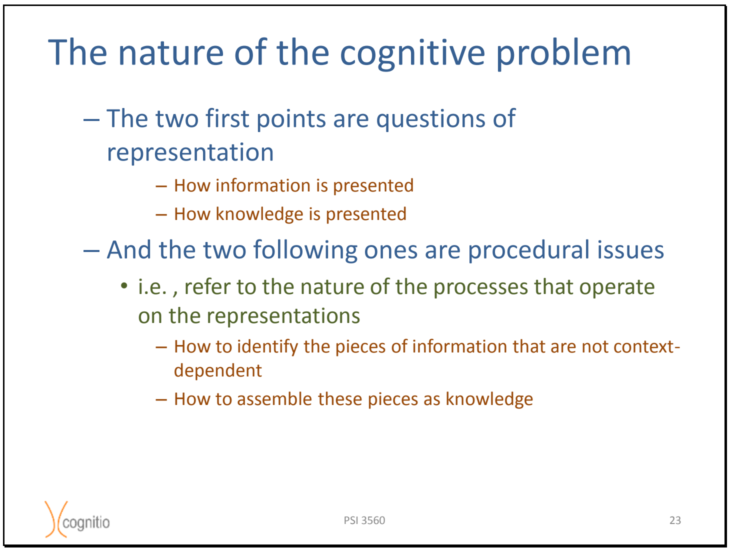


Inside of the first computational problem of cognition, there are several issues to be addressed:

- Representational issues
    - How information is presented
    - How knowledge (that is a special kind of information) is presented
- Identification issue
    - How to identify the pieces of information that do not change when the context changes, or how to detect invariant information
- Construction issue
    - How to assemble the invariant pieces of information into knowledge

Actually, there are no simple answers for each one of the questions, and currently they are still object of intense research, both theoretical and empirical. However, it is essential to keep in mind what are the questions, and to know the current, although not definitive, answers.

Slide 23



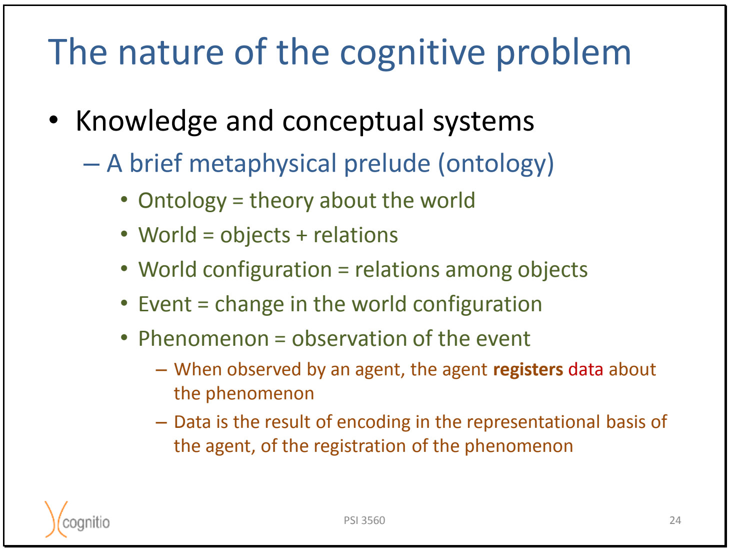
The representational questions require that we are able to characterize general information and knowledge in ways that make it possible to tell them apart.

The other two issue are procedural ones, i.e. they refer to processes:

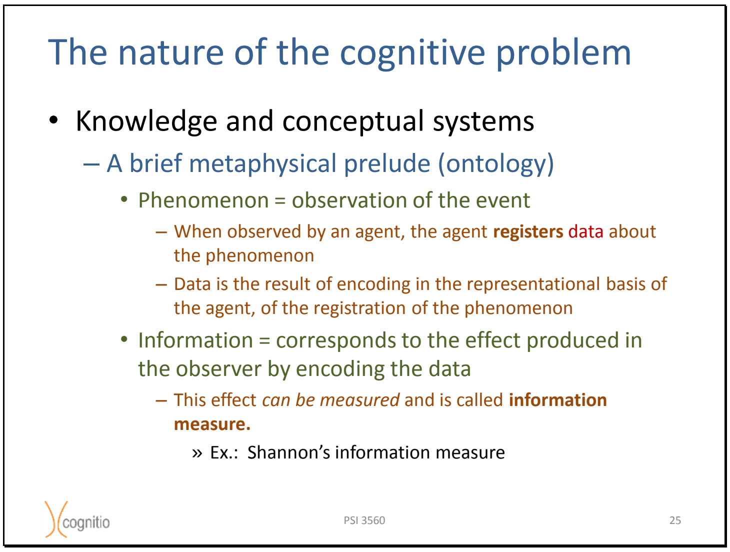
- Process of identification or detection
- Process of construction or assembling

To talk about these aspects we need to make more precise certain concepts. We previously considered information as a primitive concept and just characterized knowledge, starting from the premise that it is a special kind of information, which was taken as a primitive, and just emphasized its specific aspects, which were of being invariant to changes of context. Now, we need more than this, so we will go though some metaphysical reasoning in what follows.

Slide 24



Slide 25

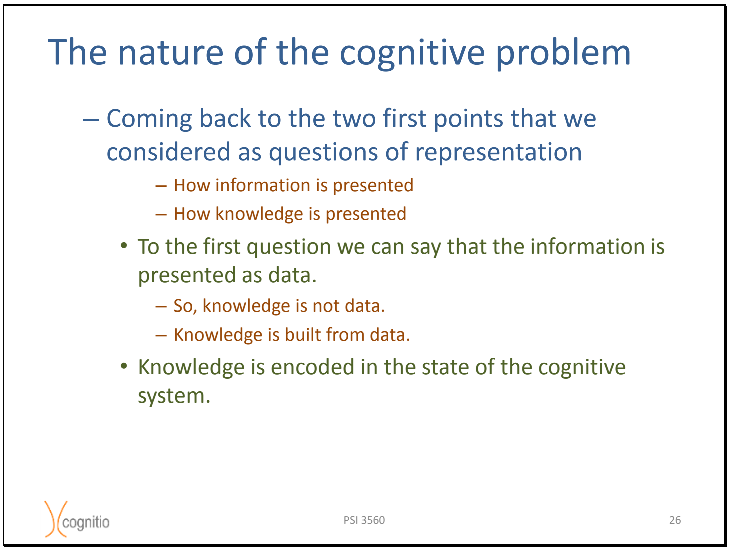


Our metaphysical considerations consists in discussing some ontological aspects concerning the nature of information and knowledge. In other words, we want to tell now in which aspects information and knowledge are different.

We start by the very idea of ontology: it is a theory about the world – what it is, what it is made of, how it is organized. So, we will go to an abstraction level that preserves only aspects relevant to the above question of how information and knowledge differ. The statements of our little ontology are on the slides above, you just have to read and think a little about them.

As an exercise, you should try to talk about your understanding of these two slides.

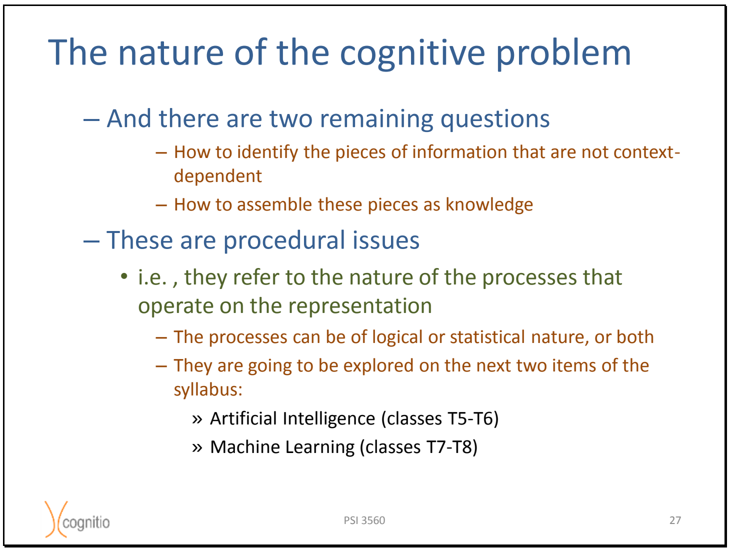
Slide 26



Using our little ontology, we can say know that information is what is contained in data. Data is something that an agent registers from its observation of some phenomenon. To register the data, the agent must grab something available in the phenomenon that conveys information. This “something” is, in physical terms, patterns of energy. For instance, if the agent is observing visually, the information is conveyed by light, that reaches the visual sensory organs of the agent (eyes, cameras). If it is hearing something, the observation is of patterns of air pressure that reaches the auditory organs of the agent. And so on.

So, the process of registration physically corresponds to the transduction of the energy patterns available in the observations into energy patterns internally used by the physical substrate of the agent (i.e., electrochemical patterns in animals, or electrical currents in electronic machines). However, as posed by Marr, the physical implementation is not relevant to the computational theory, which precedes the former. What is significant here is that the patterns of energy coming from the observed phenomenon are mapped to corresponding patterns of energy in the agent, which constitute the process of registration. Therefore, one can abstract the energy aspects and retain the fact that patterns are mapped to patterns following a determined rule. This rule is what is called encoding. Then, the data are the abstract patterns that come from this encoding. And we say that the information is the property that is preserved (or eventually altered) by this encoding process, which is a kind of mapping.

Slide 27

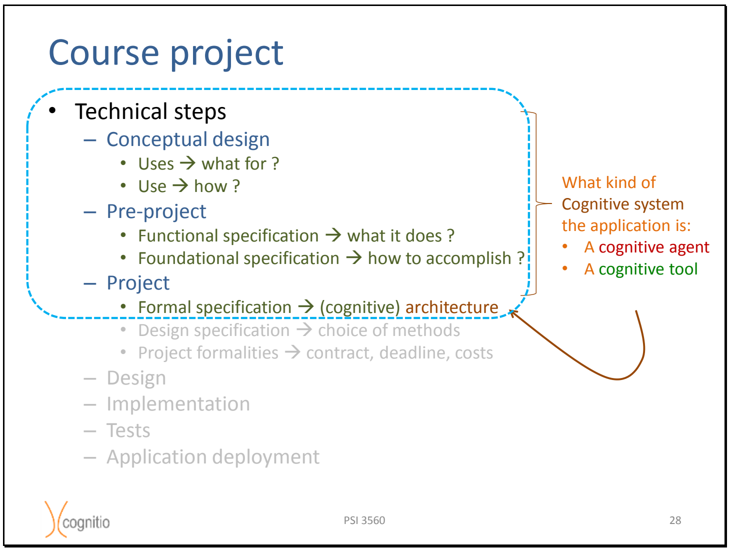


When the information gathered through an observation of an event by the agent was encoded into data, it brought all aspects of the phenomenon available to the observation process. This means that the contextual aspects of the phenomenon come together with the non-contextual ones. In order to separate them, the cognitive processes that take place in the cognitive system of the agent must employ some strategy that makes the context become apparent in contrast with what is not context. There are distinct ways of doing it and the answers were provided by several alternatives:

- Deductive reasoning and searches on solution spaces, as done by traditional artificial intelligence
- Inductive reasoning and statistical estimation, as currently done by machine learning methods
- Analytical methods based on dynamic systems modelling, as done via cellular automata, dynamic networks, evolutionary computation, etc.

The next classes will examine each of these proposals for solution confronting them with the premises of Marr's approach to modelling.

Slide 28



What can we get from all this in a practical way?

The major exercise of this course is to elaborate a project for a cognitive application.

As it was discussed since class T1, the items indicated in the slide above must be considered in this project.

To accomplish them, you must employ the concepts discussed in this class T4 and some other concepts that will be discussed in a future class (T11-T12), about cognitive architectures.

The next classes (T5 to T10) will explore aspects that will not be required for the project, because they are implementation issues such as algorithms. This project will ask you only about conceptual and specification issues.

Therefore, now you are ready to start your project and we suggest that you begin from now on.

Slide 29

You can use now this text to start thinking in practical ways of doing your project. To stimulate you, I will asked as told before that you try to summarize the points that you consider very important to preserve and pay attention and put them in a text. Select these point, talk about them telling me how you understood them. Include your eventual questions and points that you ask for clarification. We will use them during the live virtual discussion programmed for this class. I also have included some exercises that you are invited to deal with and you can include your answers to them in the text.

Put your name inside the document, your USP number, the date and the title – Class T4.

Send me your text in pdf format, single spacing. You can include pictures it necessary, but try not to use more than four pages, although I will not make this a severe restriction. I expect something between two to four pages with single spacing.

Send it via email to kogler@lsi.usp.br with the subject “Text of class T4”.

The deadline for sending me this text is April 14.

If you experience problems to attend the deadline, tell me via email before April 14.

Keep safe and healthy !