Roots of Distributed Systems
Space, Time & Computation
Distributed Systems
Sistemi Distribuiti

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1. Computer Science
2. Computation
3. Parallel, Concurrent, Distributed
Outline

1. Computer Science
2. Computation
3. Parallel, Concurrent, Distributed
As computer *scientists* and *engineers*...

- ...we are supposed to ground our technical knowledge upon some solid foundations
- accordingly, the answers to the *basic questions* should come to us without any apparent effort
Foundational Questions

- what is science?
- what is engineering?
- what is a machine?
- what is a computer?
- what is a system?
- what is a computational system?
- what is computer science?
- what is computer engineering / software engineering?
- what is computation?
What is Science?

E.g., from the Science Council

http://sciencecouncil.org/about-us/our-definition-of-science/

Science is the pursuit and application of knowledge and understanding of the natural and social world following a systematic methodology based on evidence

- well played, not really surprising
- in the overall, for all the basic questions we have answers that require some deep thinking, nevertheless they more or less belong to our background
- so, first of all, we have to find out which one is the basic question for us here
Phenomena vs. Noumena

**Phenomenon**

http://www.britannica.com/topic/phenomenon-philosophy

*Phenomenon*, in philosophy, any object, fact, or occurrence perceived or observed. In general, phenomena are the objects of the senses (e.g., sights and sounds) as contrasted with what is apprehended by the intellect. . . .

**Noumenon**

http://www.britannica.com/topic/noumenon

*Noumenon*, plural Noumena, in the philosophy of Immanuel Kant, the thing-in-itself (das Ding an sich) as opposed to what Kant called the phenomenon—the thing as it appears to an observer. . . .
What is Computer Science?

“Is there such a thing as computer science, and if there is, what is it?”

Wherever there are phenomena, there can be a science to describe and explain those phenomena. Thus, the simplest (and correct) answer to “What is botany?” is, “Botany is the study of plants.” And zoology is the study of animals, astronomy the study of stars, and so on. Phenomena breed sciences.

There are computers. Ergo, computer science is the study of computers. The phenomena surrounding computers are varied, complex, rich. [Newell et al., 1967]
What if computer science is the study of computers, yet...

*The term “computer” is not well defined, and its meaning will change with new developments.*  [Newell et al., 1967]

A science may bear a shifting object of study

*The phenomena of all sciences change over time; the process of understanding assures that this will be the case. Astronomy did not originally include the study of interstellar gases; physics did not include radioactivity; psychology did not include the study of animal behavior. Mathematics was once defined as the “science of quantity.”*  [Newell et al., 1967]
What is the Object of Study of Computer Science? II

Whatever a computer *is*, what does a computer *do*?

A computer *computes*
More generally...

- a computer is a *machine* that *computes*
- *computer systems*, or *computational systems* are systems made of computers
- computers and computational systems produce the *evidence*, the *facts*, the *phenomena* that are studied by computer science
- *computation* is then a core *object of study* of computer science
- the *essence* of *what computation is* represents then the *noumenon* at the core of computer science
Definitions of *computation* and *computer science* go hand in hand

*Over time, the definition of computer science has been a moving target. These stages reflect increasingly sophisticated understandings of computation.* [Denning, 2010]
What is the Object of Study of Computer Science? V

“The history of computer science reveals an interesting progression of definitions for computer science” [Denning, 2008]

- study of automatic computing (1940s)
- study of information processing (1950s)
- study of phenomena surrounding computers (1960s)
- study of what can be automated (1970s)
- study of computation (1980s)
- study of information processes, both natural and artificial (2000s)
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Question “What is Computation?” considered as harmful [Freeman, 2011]

*It is important to have a common understanding of fundamentals in order to make progress in any field, but a rigid “standard” that is adopted too early is almost always an impediment to progress. Just think of where we would be today if computer science had remained merely a branch of mathematics or engineering or experiment-based science.*

... said that, “What is computation?” is the basic question

- around which all Computer Science revolves
- where any well-founded study of Distributed Systems should be grounded on
What is Computation? II

Computation is Symbol Manipulation

A computation is a sequence of simple, well-defined steps that lead to the solution of a problem. The problem itself must be defined exactly and unambiguously, and each step in the computation that solves the problem must be described in very specific terms. [Conery, 2010a]

... a problem, and its solution, must be encoded in the form of symbols; a step is a symbol manipulation that transforms one set of symbols into a new set of symbols [Conery, 2010b]
Computation

What is Computation? III

Computation is Process

... the essence of computation can be found in any form of process [Frailey, 2010]

→ so, computation is a process, and every process is also a computation [Frailey, 2010]
What is Computation? IV

Process

http://www.oxforddictionaries.com/definition/english/process

`process,`

1. A series of actions or steps taken in order to achieve a particular end...
2. A natural series of changes...
3. A systematic series of mechanized or chemical operations that are performed in order to produce something...
4. An instance of a program being executed in a multitasking operating system, typically running in an environment that protects it from other processes...
What is Computation? V

When defining computation... [Denning, 2011]

- computational model matters
- many important computations are natural
- many important computations are non-terminating
- many important computations are continuous
- computational thinking can be defined
Computational Model

Computing machines
- Turing's computing machine [Turing, 1937]?
- von Neumann’s computing machine [Burks et al., 1982]?

? they are artificial, do they work when we include natural computations?

? they are discrete, do they work when we include continuous computations?

? they represent one single computing device, do they work when we deal with computational systems?
Machine, device, having a unique purpose, that augments or replaces human or animal effort for the accomplishment of physical tasks. . . . The operation of a machine may involve the transformation of chemical, thermal, electrical, or nuclear energy into mechanical energy, or vice versa, or its function may simply be to modify and transmit forces and motions. All machines have an input, an output, and a transforming or modifying and transmitting device. . . .
What is a Machine? II

Input, output & state of a machine

- *input* is what affects a machine from the outside
- *output* is how a machine affects the outside
- *state* at time $t$ is whatever is necessary to understand the evolution of a machine after $t$ given some input—or, more generally, given the *context* where the machine operates
A computing machine is a different sort of machine... 

- whose task is cognitive instead of physical
- whose input and output are basically *information*—in some form
- whose *context* is...?

Abstracting away from (computing) machinery

- if we choose not to stick with one specific computational model, it might be appropriate to *abstract away from the machinery*
- by focussing instead on the *computational process*
Computational Process I

Assumptions

- the *elementary* computational process is *sequential*
- since it represents the phenomenal expression of the dynamics of a computing machine, it has both
  - *input / output*
  - *context*
- as a result, in the following a *computing machine* is the place where a *computational process* occurs
Our representation for a computational process: *sequential computation* occur inside the blue circle.
Computational Process III

Computational process with *input* and *output*
Computational Process IV

Computational process with \textit{context}
Computational context
What is context when computation is concerned?

- *computing machine*
- resources
- time
- space
When do we need to *represent* context for computation?

Whenever either

- computing machine
- resources
- time
- space

or, all of them, are *relevant* to model / represent / understand computation—that is

- understanding the dynamics of the computational process
Computation

Context for Computation IV

**Sorts of computations**

- **timed** computation, whenever the *time* of the computational machine is relevant / essential for the computing process

- **spatial** computation, whenever the *spatial features* of the computational machine are relevant / essential for the computing process

- more generally, **situated** computation [Suchman, 1987], whenever the *environment* of the computational machine is relevant / essential for the computing process
  - where the environment is any meaningful combination of temporal and spatial features with the *resources* required by the computation
Representing context for computation

- so, understanding a computational process requires the precise definition of the computational context
- graphically, a computational process (*blue area*) depends on how we define the features of the context (*grey area*)
What is a System?

System

http://www.oxfordlearnersdictionaries.com/definition/english/system

...a group of things, pieces of equipment, etc. that are connected or work together ...
In a computational system, two or more computational processes

- *behave* (by *computing*), and
- *work together* (by *interacting*)
(Interacting) Computational System  [Goldin et al., 2006] II

Computational system
What is Context for a Computational System? I

How should we represent the context for a computational system?

- as one separate, different context for each computational process?
- as a single context for the overall computational system?
- as a combination of the above choices?
A different context for each process
What is Context for a Computational System? III

One context for all processes
What is Context for a Computational System? IV

A different context for each process plus one context for all processes
What is Context for a Computational System? V

Different contexts, different sorts of systems

The choice of the sort of the context defines the sort of the computational system, such as

- parallel systems
- concurrent systems
- distributed systems
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Parallel computing in the literature

- the term is typically used for non-sequential computing processes, where more than one computation can be performed at the same time
  [Shonkwiler and Lefton, 2006]
- typically requires *multi-core* architectures
- used to solve *computationally-intensive* scientific / mathematical problems
Concurrency in the literature

- The term is typically used with a twofold acceptation
  
  [Degano and Montanari, 1987]

  - *Interleaving*, where events occurring in separate concurrent processes could occur in *any* relative *order*—temporal / causal relations between events are not relevant
  - *True concurrency*, where *partial orderings* are used to explicitly capture temporal / causal relations between events
Concurrency vs. parallelism

- Relative ordering of events is the main point here
  - In parallel systems, events are *totally* ordered
  - In concurrent systems, events are at most *partially* ordered
- *Temporal* relation
- → *Temporal* context sets the difference
Distributed computing in the literature

- the term typically refers to a number of asynchronous computational processes located on different devices and communicating via message passing (no shared memory) [Kshemkalyani and Singhal, 2011]

Distributed computing is an activity that is performed on a spatially distributed system [Lamport and Lynch, 1990]
Distributed systems in the literature

- the term typically refer to a collection of devices working together through a network connection

A distributed system is a collection of independent computers that appears to its users as a single coherent system

[Tanenbaum and van Steen, 2007]
Distribution

- *physical distribution* of computational processes and computing devices is the main point here
  - in distributed computing, the focus is on the spatial distribution of processes
  - in distributed systems, the focus is on the spatial distribution of devices
- *spatial relation*

→ *spatial context defines both*
Definitions I

Parallel computing & systems

- given a computational system, we talk of parallel computation whenever the *temporal* context is the same for all computational process
- a parallel system is a computational system performing parallel computations
Parallel computing: the same temporal context $T$ for all processes
Definitions III

Concurrent computing & systems

- given a computational system, we talk of *concurrent computation* whenever at least two computational processes have a different *temporal* context
- a *concurrent system* is a computational system performing concurrent computations
Definitions IV

Concurrent computing: different temporal contexts $T \neq T'$ for different processes
Distributed computing & systems

- Given a computational system, we talk of distributed computation whenever at least two computational processes have a different spatial context.

- A distributed system is a computational system performing distributed computations.
Distributed computing: different spatial contexts $S \neq S'$ for different processes
Spatial vs. Temporal Contexts I

Distributed parallel computing: $S \neq S'$, same $T$
Distributed concurrent computing: \( S \neq S', T \neq T' \)
Summing Up I

Foundations
- computer science
- computation

Basic abstractions
- computational process & device
- context
- computational system
Basic definitions

- parallel computation & system
- concurrent computation & system
- distributed computation & system


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