

Roots of Distributed Systems Space, Time & Computation

Distributed Systems
Sistemi Distribuiti

Andrea Omicini
andrea.omicini@unibo.it

Dipartimento di Informatica – Scienza e Ingegneria (DISI)
ALMA MATER STUDIORUM – Università di Bologna a Cesena

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- 1 Computer Science
- 2 Computation
- 3 Parallel, Concurrent, Distributed



Next in Line...

- 1 Computer Science
- 2 Computation
- 3 Parallel, Concurrent, Distributed



Our Foundations

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 is the Object of Study of Computer Science? I

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**



What is the Object of Study of Computer Science? III

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



What is the Object of Study of Computer Science? IV

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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What is Computation? I

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]*

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,

- ❶ *A series of actions or steps taken in order to achieve a particular end. . .*
 - ❶ *A natural series of changes. . .*
 - ❷ *A systematic series of mechanized or chemical operations that are performed in order to produce something. . .*
 - ❸ *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*?



What is a Machine? I

Machine

<http://www.britannica.com/technology/machine>

***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



What is a Computing Machine?

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*

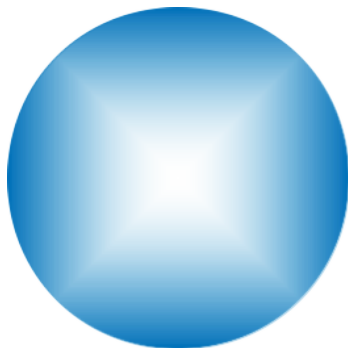
Computational Process I

Assumptions

- the *elementary* computational process is **sequential**
- since it represent 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



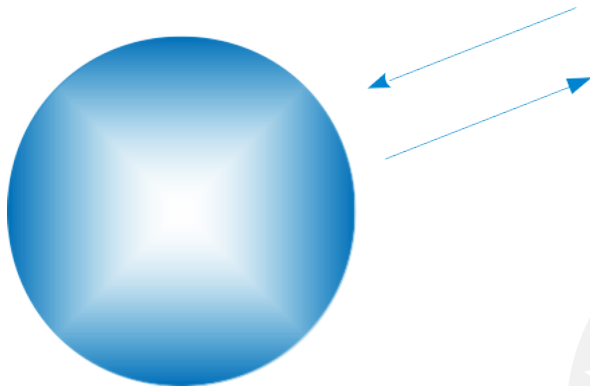
Computational Process II



Our representation for a computational process:
sequential computation occur inside the blue circle



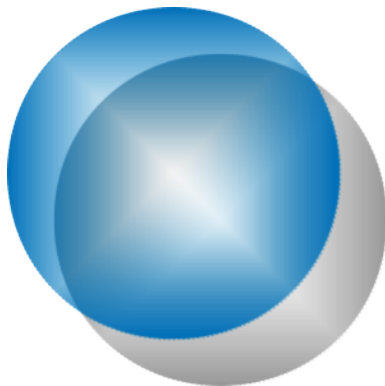
Computational Process III



Computational process with *input* and *output*



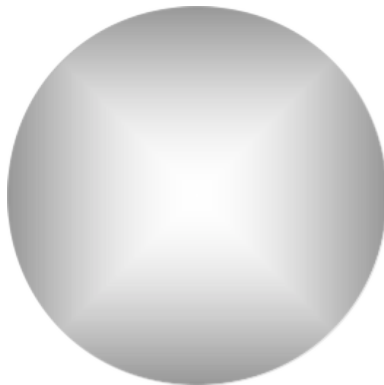
Computational Process IV



Computational process with *context*



Context for Computation I



Computational *context*



Context for Computation II

What is context when computation is concerned?

- *computing machine*
- resources
- time
- space



Context for Computation III

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



Context for Computation IV

Sorts of computations

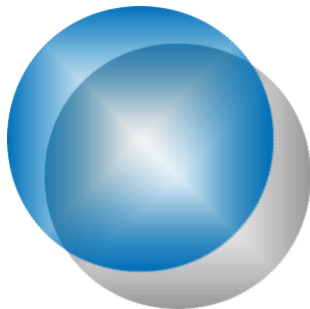
- **timed** computation, whenever the *time* of the computational machine is relevant / essential for the computing process
- **spatial** computation, whenever the *spatial features* of the computational machine are relevant / essential for the computing process
- more generally, **situated** computation [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



Context for Computation V

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 ...



(Interacting) Computational System [Goldin et al., 2006] |

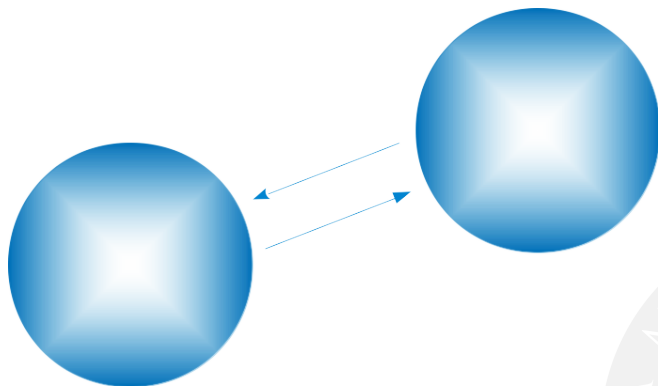
Computational system

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*



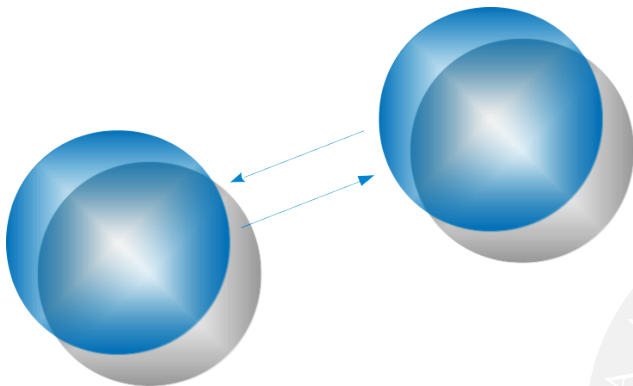
What is Context for a Computational System? I

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?



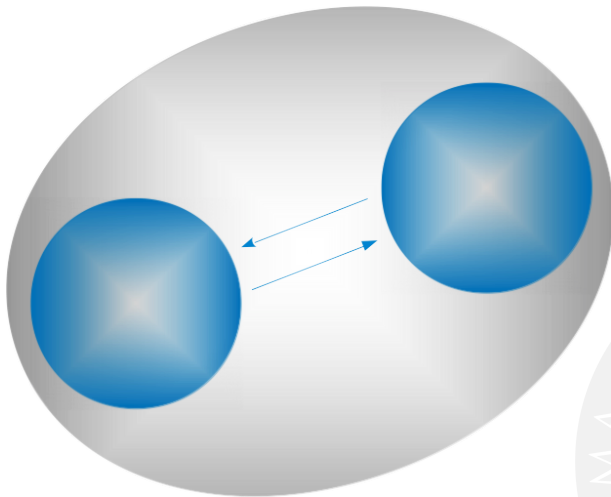
What is Context for a Computational System? II



A different context for each process



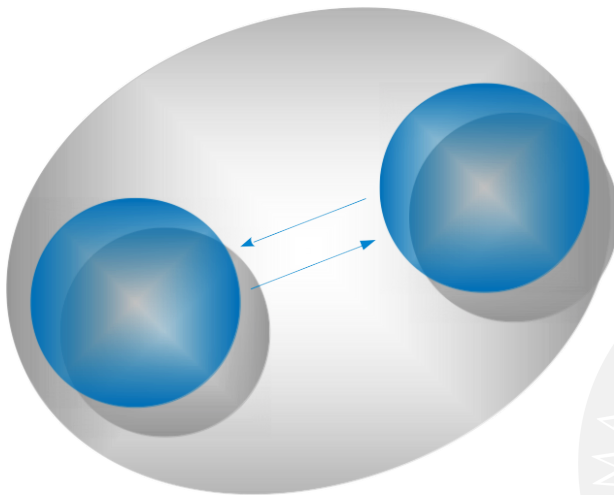
What is Context for a Computational System? III



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 vs. Concurrent Systems I

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



Parallel vs. Concurrent Systems II

Concurrency in the literature

- the term is typically used with a twofold acceptance

[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



Parallel vs. Concurrent Systems III

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 & Systems I

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 Computing & Systems II

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]



Distributed Computing & Systems III

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



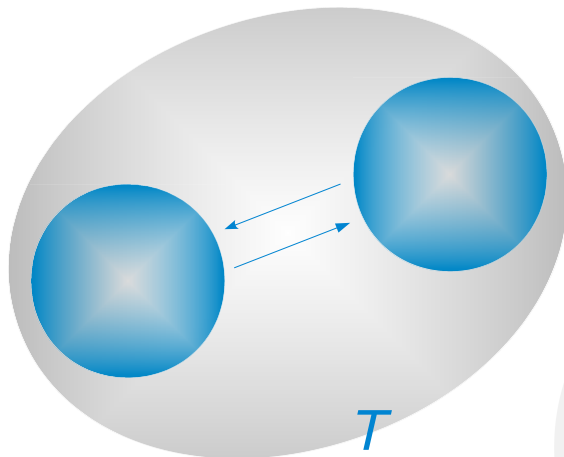
Definitions I

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



Definitions II



Parallel computing: the same temporal context T for all processes

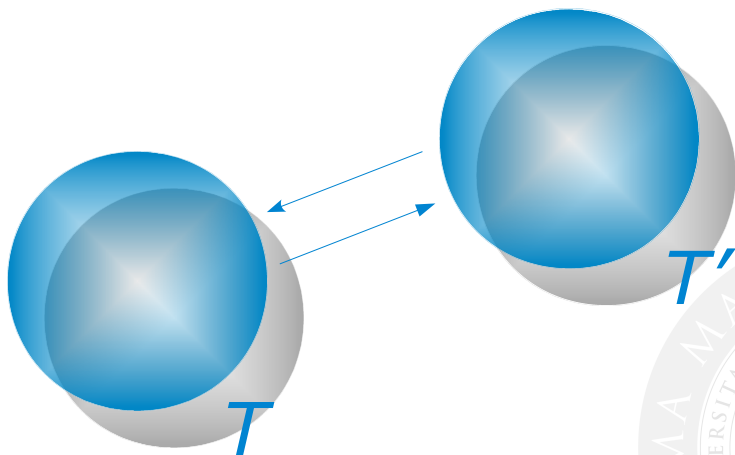
Definitions III

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

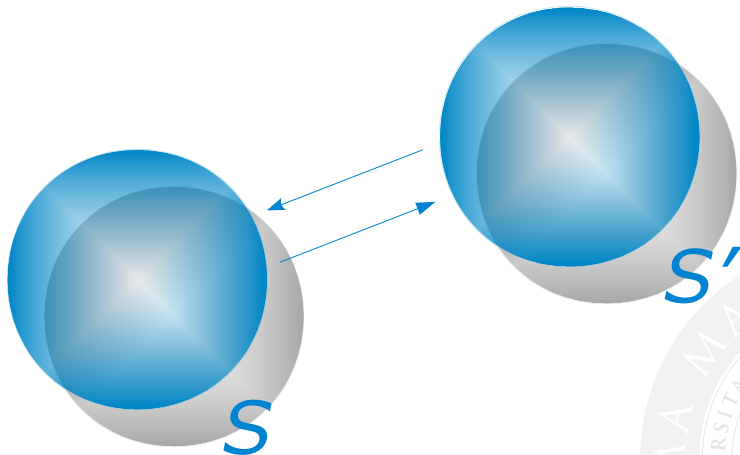
Definitions V

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

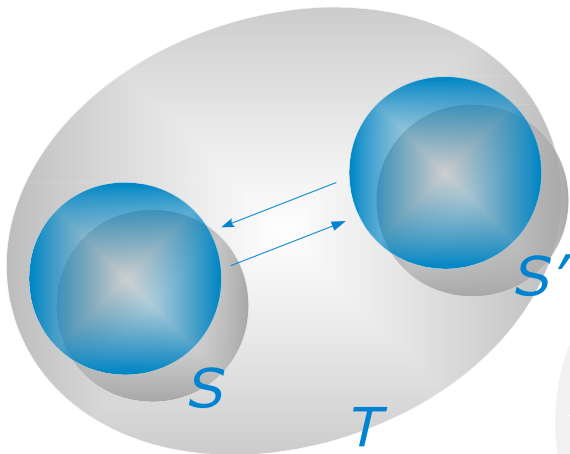


Definitions VI



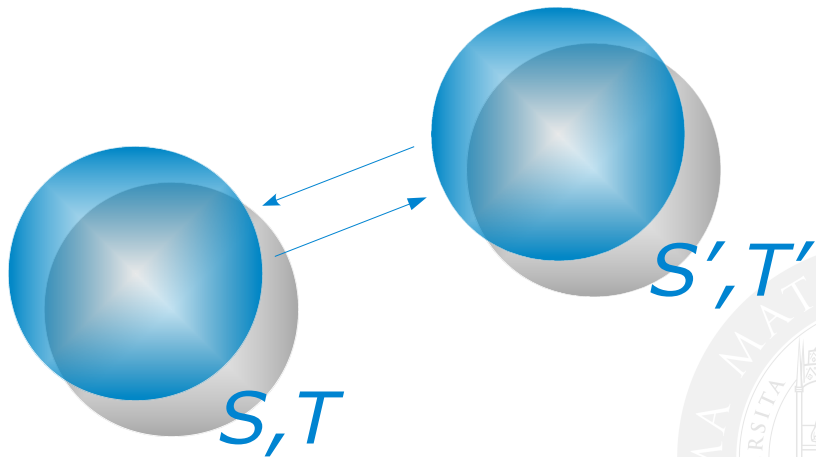
Distributed computing: different spatial contexts $S \neq S'$ for different processes

Spatial vs. Temporal Contexts I



Distributed parallel computing: $S \neq S'$, same T

Spatial vs. Temporal Contexts II



Distributed concurrent computing: $S \neq S', T \neq T'$

Summing Up I

Foundations

- computer science
- computation

Basic abstractions

- computational process & device
- context
- computational system



Summing Up II

Basic definitions

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



References I



Burks, A. W., Goldstine, H. H., and von Neumann, J. (1982). Preliminary discussion of the logical design of an electronic computing instrument. In Randell, B., editor, *The Origins of Digital Computers*, Texts and Monographs in Computer Science, pages 399–413. Springer Berlin Heidelberg, Berlin, Heidelberg.



Conery, J. S. (2010a). *Explorations in Computing: An Introduction to Computer Science*. Chapman & Hall/CRC Textbooks in Computing. CRC Press, 1st edition.



Conery, J. S. (2010b). Ubiquity symposium ‘What is computation?’: Computation is symbol manipulation. *Ubiquity*, 2010(November):4:1–4:7.



Degano, P. and Montanari, U. (1987). Concurrent histories: A basis for observing distributed systems. *Journal of Computer and System Sciences*, 34(2-3):422–461.



Denning, P. J. (2008). The computing field: Structure. In Wah, B., editor, *Wiley Encyclopedia of Computer Science and Engineering*, pages 615–623. John Wiley & Sons, Inc., Hoboken, NJ, USA.



References II



Denning, P. J. (2010).
Ubiquity symposium 'What is computation?': Opening statement.
Ubiquity, 2010(November):1:1–1:11.



Denning, P. J. (2011).
Ubiquity symposium 'What is computation?': What have we said about computation?
Ubiquity, 2011(April):1:1–1:7.



Frailey, D. J. (2010).
Ubiquity symposium 'What is computation?': Computation is process.
Ubiquity, 2010(November):5:1–5:6.



Freeman, P. A. (2011).
Ubiquity symposium 'What is computation?': Is the symposium question harmful?:
Consideration of the question 'What is computation?' considered harmful.
Ubiquity, 2011(March):1:1–1:4.



Goldin, D. Q., Smolka, S. A., and Wegner, P., editors (2006).
Interactive Computation: The New Paradigm.
Springer Berlin Heidelberg.



References III



Kshemkalyani, A. D. and Singhal, M. (2011).
Distributed Computing: Principles, Algorithms, and Systems.
Cambridge University Press.



Lamport, L. and Lynch, N. (1990).
Distributed computing: Models and methods.
In van Leeuwen, J., editor, *Handbook of Theoretical Computer Science, Volume B – Formal Models and Semantics*, chapter 18, pages 1157–1199. Elsevier.



Newell, A., Perlis, A. J., and Simon, H. A. (1967).
Computer science.
Science, 157(3795):1373–1374.



Shonkwiler, R. W. and Lefton, L. (2006).
An Introduction to Parallel and Vector Scientific Computation.
Cambridge University Press.



Suchman, L. A. (1987).
Plans and Situated Actions: The Problem of Human-Machine Communication.
Cambridge University Press, New York, NYU, USA.



References IV



Tanenbaum, A. S. and van Steen, M. (2007).
Distributed Systems. Principles and Paradigms.
Pearson Prentice Hall, Upper Saddle River, NJ, USA, 2nd edition.



Turing, A. M. (1937).
On computable numbers, with an application to the entscheidungsproblem.
Proceedings of the London Mathematical Society, s2-42(1):230–265.



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