A tutorial for ICDCN 2014

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1 Title

CHECKPOINTING AND DEBUGGING IN DISTRIBUTED COMPUTING

2 Area and duration

Area: Theory and practice of dependability for message-passing distributed systems.
Duration: 4 hours.

3 Description of the topic

This tutorial addresses two complementary topics: checkpointing and debugging (detection of properties and replay) in distributed message-passing computations.

The first part, which is on checkpointing, will introduce the notions of local and global checkpoints, and present a theorem stating a necessary and sufficient condition for a set of local checkpoints to belong to the same consistent global checkpoint. Then, it will consider two consistency conditions, which can be associated with a distributed computation enriched with local checkpoints. The first consistency condition (called z-cycle-freedom) ensures that any local checkpoint, which has been taken by a process, belongs to a consistent global checkpoint. The second consistency condition (called rollback-dependency trackability) is stronger. It states that a consistent global checkpoint can be associated on the fly with any local checkpoint (i.e., without additional communication). The tutorial will discuss these consistency conditions and present algorithms that, once superimposed on a distributed execution, ensure that the corresponding consistency condition is satisfied. It will also present a message logging algorithm suited to uncoordinated checkpointing.

The second part of the tutorial will be devoted to the debugging of asynchronous message-passing computations. Distributed programs are more difficult to design than sequential programs. This is mainly due to asynchrony which makes the notion of a global state difficult to master and exploit. It follows that distributed debugging of distributed programs is much more difficult than its sequential counterpart. Two fundamental issues are attached to distributed debugging: the replay of distributed executions and the detection of global properties of these executions, mainly when these properties are unstable (while, once true, a stable property remains true forever, this is no longer the case for unstable properties). The tutorial will discuss these two important issues and will present several approaches and algorithms that have been proposed to solve them.
As for a lot of topics related to distributed computing, the literature on distributed checkpointing or distributed debugging is mainly restricted to technical papers (which presents experimental results) or theoretical papers (which focus on theorems and lower bounds). The tutorial is destined to the people who are not familiar with the concepts related to distributed checkpointing and debugging, and want to quickly understand their aim, their basic principles, their power and limitations. The tutorial will adopt an algorithmic approach to explain these concepts. Moreover, whatever the problem they have to solve, one aim of the tutorial is to enlarge the knowledge and the background of researchers and engineers whose main interest is distributed dependability. This tutorial is devoted to the debugging of asynchronous message-passing computations.

4 Structure and technical content

4.1 Distributed checkpointing

1. Introduction

2. Base definitions and the fundamental theorem

3. Consistent checkpoint abstractions
   (a) Cycle-freedom in the checkpointing graph
   (b) Rollback-dependency trackability (RDT)
   (c) A global picture of distributed checkpointing algorithms

4. Checkpointing algorithms ensuring cycle-freedom
   (a) Operational characterization of z-cycle-freedom
   (b) A property of a timestamping system
   (c) Simple algorithms ensuring z-cycle-freedom

5. Checkpointing algorithms ensuring the RDT property
   (a) Why rollback-dependency trackability is important
   (b) The Fixed-dependency-after-send strategy
   (c) A more sophisticated but much better algorithm

6. Message logging in uncoordinated checkpointing
   (a) Uncoordinated checkpointing
   (b) To log or not to log on stable storage: that is the question
   (c) An associated recovery algorithm

7. Conclusion
4.2 Distributed debugging

1. Introduction and base definitions
   (a) Distributed programs, the notion of a race
   (b) An execution is a partial order

2. Replay of distributed executions
   (a) Curtie-Wittie’s logging method
   (b) Replay the whole or a part of an execution
   (c) Replaying a subset of processes only
   (d) Netzer-Miller’s optimal tracing
   (e) On the fly replay

3. Detection of properties on distributed executions
   (a) Detection of properties on control flows
   (b) Detection of a conjunction of stable local predicates
   (c) Detection of stable properties on global states
   (d) Detection of unstable properties on global states

4. Conclusion

4.3 Material


5 The audience

This tutorial is aimed at:

- Practitioners who want to understand the basics of distributed checkpointing, distributed debugging, and related dependability issues.

- Master/PhD students involved in failure-prone distributed systems or parallel systems, who
  want to understand the fundamental concepts that have been stated and investigated, know
  their power and limitation, and be able to put them into practice.

The attendees will acquire a solid knowledge on distributed checkpointing and distributed debugging techniques: what are the main issues and how to solve them. A fundamental statement is the following: “When a solution works, we should know why it works. When a solution does not work, we should know why it does not work”. The tutorial will help people make this statement true, when they have to understand or implement distributed checkpointing or distributed debugging mechanisms suited to asynchronous message-passing systems.
6 Biographical sketch

Michel Raynal has been a professor of computer science since 1981. At IRISA (CNRS-INRIA-University joint computing research laboratory located in Rennes), he founded a research group on Distributed Algorithms in 1983. His research interests include distributed algorithms, distributed computing systems, networks and dependability. His main interest lies in the fundamental principles that underly the design and the construction of distributed computing systems. He has been Principal Investigator of a number of research grants in these areas, and has been invited by many universities all over the world to give lectures on distributed algorithms and distributed computing. He has supervised more than 45 PhD students, and his h-index bypasses 50.


Michel Raynal has written 10 books devoted to parallelism, distributed algorithms and systems (MIT Press and Wiley). In the recent past, he has written two books devoted to fault-tolerant distributed systems, both published by Morgan & Claypool, “Communication and Agreement Abstractions for Fault-Tolerant Asynchronous Distributed Systems” (June 2010) and “Fault-tolerant Agreement in Synchronous Message-passing Systems” (September 2010). His book on fault-tolerant synchronization in shared memory systems, titled “Concurrent Programming: Algorithms, Principles, and Foundations” (515 pages) has been published very recently in early 2013, 500 pages). His last book book titled “Distributed Algorithms for Message-Passing Systems” (appeared in July 2013) is devoted to the basic algorithmic knowledge on distributed computing that students should master at the end of their Master degree.

Professor Michel Raynal has been an invited speaker in more than 20 international conferences (including the prestigious DISC, Europar, ICDCN, OPODIS and NCA conferences). He belongs to the editorial board of several international journals (including JPDC, IEEE TC, JCSSE and FDCS). He has served in program committees for more than 150 international conferences (including ACM PODC, DISC, ICDCS, IPDPS, DSN, LADC, SRDS, SIROCCO, etc.) and chaired the program committee of more than 25 int’l conferences (including DISC -twice-, ICDCS, ICDCN, OPODIS, SIROCCO and ISORC). He has also been general chair of several major conferences. Moreover, Michel Raynal served as the chair of the steering committee leading the DISC symposium series in 2002-2004, and was a member of the steering committees of ACM PODC (ACM Symposium on the Principles of Distributed Computing) and SIROCCO (Colloquium on Structural Information and Communication Complexity). He is currently member of the steering committees of ICDCN (Int’l Conference on Distributed Computing and Networks) and IEEE ICDCS (Int’l Conference on Distributed Computing Systems). He is also the European representative in the IEEE technical committee on Distributed Computing.

Michel Raynal received the IEEE ICDCS “Best Paper” award three times in a row: 1999, 2000 and 2001. Recently, he also received the “Best Paper” award at the Int’l conference SSS 2009, the “Distinguised Paper” award at EUROPAR 2010, and the “Best Paper” award at DISC 2010 and SSS 2011. Since 2010, Michel Raynal is a senior member of the very prestigious ”Institut Universitaire de France”.

More information can be obtained at http://www.irisa.fr/prive/michel.raynal/ or, as far as publications are concerned, from DBLP, CiteSeer, or any other system.