Chapter 8.10
An Operational Semantics of Real–Time Process Algebra (RTPA)

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ABSTRACT

The need for new forms of mathematics to express software engineering concepts and entities has been widely recognized. Real-time process algebra (RTPA) is a denotational mathematical structure and a system modeling methodology for describing the architectures and behaviors of real-time and nonreal-time software systems. This article presents an operational semantics of RTPA, which explains how syntactic constructs in RTPA can be reduced to values on an abstract reduction machine. The operational semantics of RTPA provides a comprehensive paradigm of formal semantics that establishes an entire set of operational semantic rules of software. RTPA has been successfully applied in real-world system modeling and code generation for software systems, human cognitive processes, and intelligent systems.

INTRODUCTION

Real-time process algebra (RTPA) is a denotational mathematical structure and a system modeling methodology for describing the architectures and behaviors of real-time and nonreal-time software systems (Wang, 2002, 2003, 2006a, 2006b, 2007a, 2008a-c). RTPA provides a coherent notation system and a rigorous mathematical structure for modeling software and intelligent systems. RTPA can be used to describe both *logical* and *physical* models of systems, where logic views of the architecture of a software system and its operational platform can be described using the

same set of notations. When the system architecture is formally modelled, the static and dynamic behaviors that perform on the system architectural model, can be specified by a three-level refinement scheme at the system, class, and object levels in a top-down approach. Although CSP (Hoare, 1978, 1985), the timed CSP (Boucher & Gerth, 1987; Fecher, 2001; Nicollin & Sifakis, 1991), and other process algebra (Baeten & Bergstra, 1991; Milner, 1980, 1989) treated a computational operation as a process, RTPA distinguishes the concepts of meta processes from complex and derived processes by algebraic process operations.

Definition 1: *Operational semantics of a programming language or a formal notation system is the semantics perceived on a given virtual machine, known as the abstract reduction machine, that denotes the semantics of programs or formal system models by its equivalent behaviors implemented on the reduction machine.*

One way to define an operational semantics for a language or formal notation system is to provide a state transition system for the language, which allows a formal analysis of the language and permits the study of relations between programs (Jones, 2003; Plotkin, 1981; Schneider, 1995). An alternative way is to describe the operations of the language on an abstract deductive machine whose operations are precisely defined (Sloneger & Barry, 1995; Winskel, 1993). In operational semantics, the reduction machine is a virtual machine that is adopted for reducing a given program to values of identifiers modeled in the machine by a finite set of permissible operations (Louden, 1993; McDermid, 1995).

This article presents a comprehensive operational semantics for RTPA on the basis of an abstract reduction machine, which defines inference rules for repetitively reducing a system model in RTPA into the computational values of identifiers and data objects. The abstract syntaxes

of RTPA are introduced, and the reduction machine of RTPA is elaborated. Based on these, the operational semantics of 17 RTPA meta processes and 17 RTPA process relations are systematically developed. A comparative analysis of a set of comprehensive formal semantics for RTPA may be referred to (Wang, 2007a). The *deductive semantics* of RTPA is presented in Wang (2006a, 2008b). The *denotational semantics* of RTPA is reported in Tan and Wang (2008).

THE ABSTRACT SYNTAX OF RTPA

On the basis of the process metaphor of software systems, abstract processes can be rigorously treated as a mathematical entity beyond sets, relations, functions, and abstract concepts. RTPA is a denotational mathematical structure for denoting and manipulating system behavioral processes (Wang, 2002, 2003, 2006a, 2006b, 2008a-c). RTPA is designed as a coherent algebraic system for software and intelligent system modeling, specification, refinement, and implementation. RTPA encompasses 17 meta processes and 17 relational process operations.

Definition 2: *RTPA is a denotational mathematical structure for algebraically denoting and manipulating system behavioural processes and their attributes by a triple, that is:*

$$RTPA \triangleq (\mathfrak{T}, \mathfrak{P}, \mathfrak{N}) \qquad (1)$$

where

- $\mathfrak{T}$ is a set of 17 primitive types for modeling system architectures and data objects;
- $\mathfrak{P}$ a set of 17 meta processes for modeling fundamental system behaviors;
- $\mathfrak{R}$ a set of 17 relational process operations for constructing complex system behaviors.

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