一・項目簡介

（*項目所屬科學技術領域、主要研究內容、發現點、科學價值、同行引用及評價等內容。*）

Advances in Software Engineering (SE) have enabled ICT to provide solutions to many complex problems in domains where it used to be infeasible to find practical solutions. This has led to the increase in software complexity. Complexity is the inherent source of the long lasting software crisis. A complex system is open to total breakdown and consequences of system breakdowns are sometimes catastrophic and always very costly. Given that the global economy, as well as our everyday life, depends on software systems, a grand challenge in SE is to advance the theories and techniques for mastering the increasing software complexity and develop more reliable system development procedures. *Model-driven architecture* (MDA) has emerged as a mainstream effort in searching for solutions to the challenge.

The main scientific principle behind MDA is that the complexity of software development can only be mastered by building, analyzing and manipulating *system models*. The main technique is that models are decomposed into components and they are built in *different levels of abstraction* in different stages of project development. It is crucial to support independent component design, implementation and deployment, in either a top-down or a bottom-up development process. Therefore, for a model-driven method to be applied effectively, it must provide a body of techniques and an integrated suite of tools for *model construction, validation and transformation.* This requires a number of modeling notations for different design concerns and viewpoints. These notations should have a formally defined syntax and a *unified theory of semantics* to underpin the development of valid techniques and tools, as well as to formally verify and reason about properties. The modeling notations, techniques and tools must be designed such that they can be used seamlessly in supporting development activities in software design processes.

The method of rCOS – *Refinement of Component and Object Systems* – is a formal MDA method jointly developed by UNU-IIST and the University of Macau during 2001 – 2011. **The research has received support from FSTDM through projects during 2006-2011**. The method consists of the following four strands:

1. **The rCOS Unified Theory of Models** defines a modeling notation (called RCOSP) and its operational and denotational semantics that support specification of different view points of architectural components, including their *interface services*, *local data functionality* of services, *interaction protocols*, and *dynamic behavior* of components. The notation also defines *architectural composition operators*.
2. **The rCOS Calculus of Refinement** relates models at different levels of abstraction, from component interface contracts, through models of designs at different stages, to implementations. A complete set of valid *rules of refinement* are provided and used to prove OO *design patterns* to support *correctness-preserving design*. The completeness here means that this set of rules are powerful enough to characterize all possible correct changes of a program specification.
3. **Techniques and algorithms** are developed based on the theory and the refinement calculus for checking model consistency – both structural and dynamic behavior – among models of different viewpoints, and for model transformations.
4. **The rCOS modeler** is a transformation driven tool developed for a well-defined UML profile for rCOS. It supports graphic model construction, implements the algorithms of consistency checking, realizes the design patterns as model transformations, and generates proof obligations to invoke model checking and theorem proving tools. Component-based testing techniques and algorithms have also been implemented.
5. **Experiments** are carried out on the CoCoME component-based modeling benchmark that was proposed at a workshop in Europe, a university library and healthcare workflows. They demonstrate the applicability of the theory and the effectiveness of the techniques and the tool.

Research outputs: Over 60 papers have been published in mainstream international journals and proceedings of major international conferences on theoretical computer science. Among them, 12 are included in SCIE, 38 in EI and 40 CPCI.

Impact: Google Scholar citation search finds 336 are non-self citations. Among them 33 citations in SCIE and 162 EI. There are also technical reports, as well as PhD and Master theses that direct work with rCOS. Furthermore,

- Three projects on further development of rCOS, funded by the Chinese National Nature Science Foundation (CNSF), are taking place at the Institute of Software of the Chinese Academy of Sciences (ISCAS), East China Normal University (ECNU) and National University of Defense Science and Technology, respectively.
- Seven more projects have been developed based on or using rCOS: an Academy of Sciences Distinguished Young Researcher's project at ISCAS, a Ministry of Science and Technology 863 Project and a project within the CNSF project at ECNU, a CNSF project at Tongji University, a project at Nanjing University funded by the Ministry of Education, and two projects at Shandong Academy of Sciences Funded by Shandong Province.

Details of these projects are given in Part 4 of this form.

Over 30 UNU-IIST fellows and 10 postdocs have been trained on the rCOS research. Six of the fellows completed their PhD theses and 5 their Master theses with their work on rCOS. Three PhD students are currently working on rCOS and two of them will finish this year.

Parts of rCOS have been taught in two Master courses at ECNU, Bachelor course at Graz University of Technology (Austria), San Agustin University and San Pablo University in Peru, and a PhD course at Pisa University (Italy), as well at course at the University of Macau and UNU-IIST. The rCOS method is also used in student projects at ECNU, San Agustin University and San Pablo University. The researchers of rCOS have been often invited to teach rCOS and give seminars in universities of the world. Zhiming Liu gave keynotes on rCOS at four international conferences and taught rCOS at a large number of international summer schools. We received interns to study rCOS, as well as many research visitors, from many parts of the world.

The development of effective MDA methods for reliable software design forms an important part of the international program on the Grand Challenge of Verified Software proposed at the end of last century by Sir Professor Tony Hoare, an ACM Turning Award Winner. Indeed, the Grand Challenge inspired the joint research project of UNU-IIST and the University of Macau on rCOS and Sir Prof. Hoare gave his support in our project proposals. The research on rCOS has also opened new directions of research in the area of performance critical and cyber-physical architectures, and applications of distributed and web-based software systems.

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