COMPOSITIONAL APPROACH TO PROGRAM FORMALIZATION AND VERIFICATION
(methodological introduction)

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Introduction

- In the current computing curricula specialization prevails over integration
- This leads to some negative consequences
- Specialization and integration should be balanced
- The aim of the lecture is to present an integrative composition-nominative approach to programming-related disciplines
Specialization-Integration Cycle in Theories Development
Integration between Formal Methods

Prof. Wolfgang Schreiner*: The RISC ProgramExplorer was developed to provide a close integration between programs, theories, specifications, and semantic models. This is "horizontal" integration. Next step - "vertical" integration

*Computer-Assisted Program Reasoning Based on a Relational Semantics of Programs
Goals of Integrative Approach

- **Scientific:** Explication and formalization of semantic-based methods of software system development

- **Educational:** development of a new content for computer science disciplines “around” programming

- **Practical:** Construction of software and educational systems based on the proposed integrative approach
Integrative approach (educational aspects)

Aim: construct main parts of programming-related disciplines in integrity of their essential aspects using a relatively small number of

- methodological principles,
- basic notions, and
- formal models.

Integration strongly correlates with fundamentalization that emphasizes importance of fundamental, basic notions for professional education
Programming-related disciplines

They include disciplines of three groups:

1) concerning programming itself,

2) basic for programming like theory of algorithms (computability theory), mathematical logic, universal algebra, theoretical linguistics, and

3) based on or involving programming like system specification, validation and verification, formal methods of software development, requirement analysis, etc.
Methodological principles

- **Principle of universal connection**: everything is connected with something else.

- **Principle of development from abstract to concrete** (from simple to complex, from a lower level to a higher one, from the old to the new).

- **Triadic principle of development**: thesis – antithesis – synthesis

- **Principle of unity of theory and practice** (variant: union of logical and historical development).
Integration of theory and practice in notion explication

Theory
- Categories
  - Scientific notions
  - Formal notions

Practice
- Society
- Education
- Transport
- Informatization (Computing)
Summary of the proposed approach

- Integration
- By Development
- From Abstract to Concrete
- From Methodological via Professional to Mathematical Level (vertical integrity)
- With Internal Integrity on each Level (horizontal integrity)
Main Subject-Object Relations (philosophical level)

- **Ontological**
- **Gnosiological (Epistemological)**
- **Praxeological**
- **Axiological**
- **Phenomenological**
- ...

*We advocate importance of teaching philosophy (in view of knowledge-based economy)*
Expected Results (ontological level)

- Net of Notions (Ontology)
- on various levels
- with relations between them

Transformations between levels:
- particularization,
- formalization.
Basic Disciplines for Theory of Programming (mathematical view)

Theory of Programming

- Computability Theory
- Universal Algebra
- Mathematical Logic
- Set Theory

Theories are not fully adequate with Theory of Programming, adaptation is required.
Proposed Dependency Scheme (Algebraic approach)

Theories are integrated with Theory of Programming, are built on one basis, adaptation is not required.
Developing the main notions of Programming

Linz, JKU, November 08-19, 2012
Main Methodological Principles (professional level)

- Principle of integrity of intensional and extensional aspects (particularization of categories universal-particular-singular); leading role of intensional aspects

- Descriptivity principle: objects are presented by their descriptions; semantic and syntactic aspects are particularization of categories content-form; leading role of semantics over syntax

- Compositionality principle

- Nominativeness principle
Pentad of the main basic program notions

PROBLEM

PROGRAM

DATA

FUNCTION

NAME

DESCRIPTION

COMPOSITION

applicativity

interpretation

application

grammatical

interpretation

denoting aspect

syntactic aspect

semantic aspect

naming

Main thesis (professional level)

The main notion of computer science (informatics) is the notion of *language* (primarily in constructive, formal, communicative, and practical aspects)
Development of the notion of data

Triads of categories:
whole (W) – parts (P) – synthesis (H as Hierarchy)
abstract (A) – concrete (C) – synthesis (S).

**FUNCTION**

**DATA**

- Level W (Whole)
  - W.A – “black box”
  - W.C – “white box”
  - W.S – “white or black box”

- Level P (Parts)
  - P.A – presets
  - P.C – sets
  - P.S – flat nominative data

- Level H (Hierarchy)
  - H.A – hierarchic presets
  - H.C. – hierarchic sets
  - H.S – hierarchic nominative data
Nominative data

- Nominative data are based on the naming relation \textit{name}→\textit{value}

- Values can be \textit{simple} (unstructured) or \textit{complex} (structured)

- Names can be \textit{simple} or \textit{complex}

- Names and values can be \textit{independent} (direct naming) or \textit{dependent} (indirect naming is allowed)
Representation principles

Data representation principle:
program data can be represented as concretizations of nominative data.

Semantics representation principle:
program semantics can be represented by functions over nominative data (nominative functions) constructed with the help of compositions
Formal language model
(mathematical level)

The first formal language model –

Composition-Nominative Model:

- Semantic (Composition) System
- Syntactical System
- Denotational System

Composition System:

Data – Function – Composition

Intensions should be taken into account
Semiotic Aspects of Programs

- pragmatic
- semantics
- Syntax

Semiotic aspects are too abstract, pragmatics is overloaded with various senses.
Richer theory of aspects is required
Essential Program Aspects

- **External program aspects:** adequacy, pragmatics, computability, and origination;

- **Internal aspects:** semantics, syntax, and denoting relation

- Relations between external and internal aspects (process of programming and composition, process execution and function application, etc.)
Integrating programming with computability theory

- Traditional computability is understood as computability of n-ary functions defined on integers or strings (Turing computability, fixed intension).

- The notion of computability over classes of data with different intensions is required.
Natural computability

Diagram of natural computability
Complete classes

Theorem 1. $\text{Comp}(IA, D) = \{ \bot, id \}$.

Theorem 2. $\text{Comp}(IC, D) = D \rightarrow D$.

Theorem 3. $\text{Comp}(IAC, A \cup C) = \{ f \cup g \mid f \in \{ \bot_A, id_A \} \cup \{ A \mid c \in C \}, g \in C \rightarrow C \}$.

Theorem 4. $\text{Comp}(IND, ND(V,W)) = CLOS(\{ \Rightarrow v_0, \ldots, \Rightarrow v_m, v_0 \Rightarrow, \ldots, v_m \Rightarrow, v_0!, \ldots, v_m! \}, \{ ^\circ, *, \nabla \})$.

Theorems describes executable components of program specification
Integrating programming with mathematical logic

The main notions of logic:

\((IMW, ECW, L, Int, |=, |–)\)

- \(IMW\) is an intensional model (of worlds),
- \(ECW\) is a class of extensional models,
- \(L\) is a language of a logic,
- \(|=\) is a validity relation, and
- \(|–|\) is an inference relation.
Main notions of Logic

Language – formulas (Syntactic aspect)

Models of Worlds (semantic aspect)

Intensional Model

M1

M2

…………

Interpretations I

Inference |- Validity and Completeness

Validity |=
Classes of logics

With respect to the intensions of data we can specify the following predicate logics:

- propositional logics (abstract data),
- singular logics (concrete data),
- renominative, and
- quantified logics (nomnitive data).

For all these logics composition-nominative languages of predicates are defined and investigated.

Next level –program logics.
Conclusions

Programming-related disciplines:
- Theory of Programming
- Theory of Algorithms
- Mathematical Logic
- Universal Algebra
- Specification and Programming Languages
- Formal Methods of Software Development
- Databases

can be taught on one (methodological, professional and formal) basis.

Constructed models are formal thus permitting their thorough investigation with further implementation of e-learning tools.
References

Formal definitions are presented in:


Thank you!
Questions?