On the Status of the ISAC-Project
Report No. 1

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The ISAC-project has been ongoing for several years and has now reached a status which requires a report for efficient continuation. The date of the rejection of the proposal for an F&E grant by the FWF\(^1\) is an occasion for such a first report on the activities undertaken, on what has been achieved so far and what is planned for the next future. This report is intended to give an account for the participants as well as for the mentors of the project, to inform the partners in cooperations – already established or envisaged – as well as potential users who already declared their interest in ISAC.

1 Activities performed

The project started some time in between 1977 and 2000, when the design work of Walther Neuper under the supervision of Peter Lucas and Bruno Buchberger came to the conclusion, that essential gaps in the offerings of presently available mathematics systems can actually be filled [Neu99a, Neu99b, Neu01b].

1.1 Software development

Software development has been done completely within seminar-projects and diploma theses which were all accompanied by substantial design work.

- The base for this work has been done by Walther Neuper designing the structure of the knowledge base and implementing the knowledge interpreter during a sabbatical year in 1999/2000 and has been continued during two halve-time sabbaticals 01/02 and 02/03 respectively.

- Front-end prototyping has been done by Thomas Fink as a diploma thesis [Fin00] under supervision by Peter Lucas in 1999/2000. This prototype still serves for demonstration.

- Multi-user system prototyping and interconnection of SML and Java has been done by Thomas Oberhuber as a seminar-project under supervision by Walther Neuper in 99/00.

- Simplifying multivariate fractions was the first portion of knowledge implemented consistently. This has been done by Stefan Karnel as a diploma thesis [Kar02b] under supervision by Clemens Heuberger in 2001/02.

- Elementary equations over polynomials, rationals and square-roots have been implemented as the first part of the hierarchy of problem-types by Richard Lang as a diploma thesis [Lan03] supervised by Peter Lucas.

- Algebraic simplification of polynomials, rationals and square-roots is under construction by Matthias Goldgruber as a seminar/project supervised by Walther Neuper; this work will be continued as a diploma thesis supervised by Franz Wotawa.

- Architectural and software design has been started by Alan Krempler and Andreas Griesmaier within their diploma theses (supervisors Peter Lucas and Franz Wotawa respectively) together with Walther Neuper in cooperation with Klaus Schmaranz and his Dinopolis-team in 2002.

2 www.dinopolis.org

3 The page www.ist.tugraz.at/projects/isac/status.html contains the design documents under construction.
1.2 Cooperations

Cooperations have been initiated in a wide range according to the variety of challenges evoked by the complexity of *ISAC* as planned:

- **Institutes for Mathematics** provide the expertise for implementing the mathematics knowledge base. Clemens Heuberger at the institute at TU Graz already supervises diploma theses, the institute at TU Vienna (Dietmar Dorninger) expressed interest after an *ISAC*-presentation in Oct.01.

- **The Dinopolis-project** developing a middle-ware for distributed systems under Klaus Schmaranz [Sch02] at TU Graz, provides the components for the web-based multi-user system (students of particular courses, authors, course-admins etc.). *ISAC* is envisaged as a demonstration project for Dinopolis.

- **The Isabelle developer team**[4] at TU Munich under Tobias Nipkow has been visited in Nov.01. They promised technical support for optimizing *ISAC*’s interfaces to Isabelle; an implementation of floating-point numbers in Isabelle (used by *ISAC*) would be a topic for cooperation.

- **The MoWGLI-project**[5] makes XML-technology available for presenting and managing mathematics on the web. A meeting with the Bologna-group (under Andreas Asperti) at the MoWGLI-meeting during MKM in Feb.03 confirmed that *ISAC*’s architecture can take advantage of several MoWGLI-components, and that *ISAC* could serve as a demonstration project.

- **ACDCA**, the Austrian Center for Didactics of Computer Algebra[6], represents experience (the probably most longlasting and most elaborated worldwide) on algebra systems in education. Didactic analysis and supervision has been envisaged for the next *ISAC*-prototype at a meeting in June 02.

- **Polytechnic Universities (FH)** has been addressed as the first potential users for special courses, and as potential co-workers in extending *ISAC*’s knowledge base[7]. Seven experts have expressed their interest.

1.3 Publications and presentations

Due to the lack of funding participation and submissions at international high-quality academic conferences have been kept to a minimum.

• [Neu01a] presented the hierarchy of problem-types at the Calculemus workshop during IJCAR, International Joint Conference on Automated Reasoning, at Siena in June 01.

• [Neu01c] addressed didactic experts at ICTMT, the conference for teaching mathematics with technology, at Klagenfurt in August 01.

• In 2002 VISIT-ME [BK02], the conference on integrating technology into mathematics teaching at Vienna, was a first occasion of publicity for the ISAC-team [GL02, Gri02, Kar02a, Kre02, Neu02a, GGK +02].

• [Neu02b] lead to first contacts with Polytechnic Universities at the ’International Workshop on Interactive Computer Aided Learning’ at Villac in Oct.02.

• [NW02] presented a first attempt to assist problem solving before a formal specification is finished, at ITS, the workshop for ’Model Based Systems and Qualitative Reasoning for Intelligent Tutoring Systems’ at San Sebastian in June 02.

• Issues on teachers’ education8 have been started with AMMU, Arbeitsgemeinschaft für modernen Mathematikunterricht9, a still ongoing task.

• In June 2003 at Klagenfurt at the business meeting of ’Forum Neue Medien’ a poster10 confirmed the interest of Polytechnic Universities.

2 Project achievements

The activities mentioned in the previous section resulted in the following achievements.

2.1 Stable state in ISACs development

Several design and implementation cycles have the overall design confirmed appropriate and have made the implementation of the mathematics engine stable. The following components are available:

• The mathematics knowledge base with
  
  – the formal part consisting of Isabelle theories, of problems and of methods for
    
    * a simplifier for multivariate polynomials

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9http://www.ammu.at/
• the operations on rationals of multivariate polynomials (cancellation, addition etc.) [Kar02b]
• an experimental solver for equations over polynomials, rationals and square roots [Lan03]
  – the hooks for the multimedia part, where course-specific explanations (e.g. in a biology course differentiation may be explained in an other way as in a mechanics course) can be easily attached to every item of the formal part (which, in contrary, requires expertise in symbolic computation).

The knowledge interpreter consisting of
  – a rewriter for ordered and conditional rewriting
  – a problem handler for automated problem refinement (e.g. finding the appropriate type of equation)
  – a method interpreter for stepwise execution where the user can choose the next tactic (theorem) to be applied
  – a proof-handler including subproblems

2.2 Continuous developer team and cooperations

The mathematics engine as outlined above is ready to broaden the development efforts, and so is the ISAC-team: a team of at least four persons at a time engaged in overlapping periods with their successors, such that the experience with the fairly comprehensive ISAC-system is in personal tradition\(^1\).

Thus the developers team is ready for the cooperations prepared with the highly qualified partners.

2.3 Confirmed interest in the use of ISAC

Polytechnic Universities turned out to be the most appropriate partners for introducing ISAC, most interested in eLearning in general. The first use will be for bringing students to an equal level in the entry phase of their studies.

Experts from Polytechnic Universities also were the first who expressed interest in authoring ISACs knowledge and exercises for their courses in mechanics, electrical engineering, physics etc\(^2\).

2.4 Identification of topics open for research

Presentations and discussions at conferences have shown, that the ISAC-project works on a base technology for applied mathematics. This work is at the frontiers of several

\(^{1}\) see www.ist.tugraz.at/projects/isac/team.html
\(^{2}\) see ftp.ist.tugraz.at/projects/isac/publ/preproposal.ps.gz
research areas. The following areas have been identified, which seem wide enough for dissertations.

**A logical framework for applied mathematics:** There is no framework of formal logic established for applying mathematics, e.g. in assembling outputs of an algebra system for input to another subproblem. $\mathcal{ISAC}$'s meta-logic supports calculation of objects from given ones, the calculation eventually broken down into subproblems. Mathematicians did not yet care about formalizing such tasks (exceptions are [Buc00] or [Far01]) — but computer science has developed a wealth of theory from denotational to operational semantics, presumbaly suitable for this task.

**The rewriting paradigm** is a basic design decision for $\mathcal{ISAC}$: 'each step in problem solving should be justified by a rewrite' (as soon as the problem is specified).

This paradigm enforces already tricks in simplifying rationals (‘reverse rewriting’ [Kar02b]) or radicals (tricks which in turn raise challenging rewriting problems), but the paradigm can be generalized even to functional programming: functions (in $\mathcal{ISAC}$'s methods) can be presented to the user as rewrite rules. A particular question is, how to find a shortest sequence of rewrites in a term rewriting system.

**The architecture of distributed math systems** is a vivid research topic,$^{13}$ $\mathcal{ISAC}$ is bound to by combining the theorem prover Isabelle with its own components, and by being a web-based system which makes the knowledge base accessible to the users.

Systems like $\mathcal{ISAC}$ might turn out to be useful for routine work of engineers, who search math knowledge bases for problems and solutions, and who combine several software tools within the control of a consistent logical framework.

**Model-based reasoning and diagnosis** could assist the student in constructing a formal model, which then is used by $\mathcal{ISAC}$ for automated specification of an appropriate problem(-type) and a method solving this problem.

Preliminary ideas have been presented in [NW02]; remarkable results have been achieved in the somehow similar application to reactive systems constrained by formal models.

**Searchable problem classes** are already implemented in $\mathcal{ISAC}$: the equation solver [Lan03] searches a hierarchy of types (classes) of equations for this type which is appropriate for a given equation. $\mathcal{ISAC}$'s problem handler does this successfully regarding the types of objects given and to be found, and regarding the pre-condition.

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Most specific for a problem class, however, is the post-condition. It is an open research question, how to describe something like postcondition-schemas. If solved, this could be a step towards mechanical search of software specifications.

**Didactics and learning theory** will be challenged when constructing a user-model for ISAC and when designing the dialog-guide (a novel language for describing dialogs will be a task for software technology, again).

Vice versa, ISAC can be a research tool for constructivist approaches in learning theory: ISAC ’does math’, allows the students to watch (ISAC is ’transparent’ w.r.t. stepwise execution and w.r.t. the underlying knowledge) and supports the students in ’doing math themselves’.

For all these topics ISAC is a testbed which is considerably fledged out already, which will extend its knowledge base and which can expect widespread usage in the near future.

### 2.5 Thanks

*Many thanks to the many persons who made all these achievements possible, who contributed to the design of ISAC and who supported the implementation of ISAC, more or less in the background. And last not least many thanks to the students in the ISAC-team who actually brought ISAC to existence by their work without any remuneration.*

### 3 Plans for the future

Due to the rejection of our proposal for an FWF-grant the R&D efforts cannot be expanded now, as will be required to get over the twenty man-years listed in 3.3. Rather, for the next future ISAC will focus on

1. a lean development towards a small application
2. research on the logical framework, and search for (a) project leader(s) who is/are established enough to attract funding.

### 3.1 A lean development towards a small application

As long as there is no funding, the development will continue in the lean team as is, and implement the front-end such that the existing math-engines capabilites (simplification and equation solving over polynomials, rationals and square roots) can be used in an experimental setting within the next 10 months.

1. **Personnel** consists of the present ISAC-team (+ successively engaged diploma students substituting those having finished their studies)
(a) 1(+1) diploma student mathematics
(b) 2(+2) diploma students telematics
(c) 1 student trainee of software-technology at FH Hagenberg Aug. - Dec.03
(d) preliminary project leader (working as a teacher at HTL Ortweinschule)
(e) project leader(s) to be found (+ doctoral student(s))

2. Development tasks are planned (+ ev.additional ones defined by (1e)) on the
   (a) knowledge base
      i. finish the simplifiers on polynomials, rationals and square roots
      ii. simplifier (+ reverse rewriting) for radicals
   (b) knowledge interpreter
      i. export of SML-data in XML-format
      ii. interface according to the new specification [GKN02]
      iii. user-input of tactics at any position in the calculation
   (c) front-end
      i. basic Java classes for dialog, worksheet and knowledge browsers
      ii. XSLT from SML-output over MathML-content to MathML
         -presentation

3. Cooperations with
   (a) the Inst.for Mathematics in 2(a)ii
   (b) Dinopolis in 2(c)i; goal: at least 2 courses with different ’explanations’ for one item
   (c) MoWGLI in 2(c)ii; (no input of formulas yet, no search in the math knowledge base, etc.)

Depending on the results of this phase FHs will be contacted for cooperations in implementing exercises for entry-courses and in developing special knowledge.

3.2 Research on the logical framework

In the future mathematics software shall be proven sound and correct; this requirement holds particularly for educational math systems.

From the beginning ISAC has been designed as an educational system. Now it finds itself an experimental implementation in a vivid field of research where the concepts for the above requirement are not yet established. It is not the profession of the present project leader to establish such concepts in the academic field; his professional background can serve the development of ISAC and the introduction to education.
Thus particular emphasis will be laid on contacting researchers who can establish such concepts and who can attract academic funding for such research. Five of the most obvious research topics are sketched in 2.4.

3.3 Overall development of IS4C

The following table on the phases and the done and planned tasks within the IS4C-project makes clear, that the expertise from several academic fields will be required for meeting the requirements of the state of the art.

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Legend: R research, D development

Persons mentioned in this report, in alphabetical order:

- Andrea Asperti [http://www.cs.unibo.it/ asperti/]
- Bruno Buchberger [http://www.risc.uni-linz.ac.at/people/buchberg/]
- Dietmar Dorninger [http://www.algebra.tuwien.ac.at/dorninger/]

• Matthias Goldgruber, diploma student in mathematics, TU Graz
• Andreas Griesmaier, diploma student in telematics, TU Graz
• Clemens Heuberger http://finanz.math.tu-graz.ac.at/cheub/
• Stefan Karnel http://www.ist.tugraz.at/projects/isac/team/isacM01.html
• Alan Krempler, diploma student in telematics, TU Graz
• Richard Lang http://www.ist.tugraz.at/projects/isac/team/isacM03.html
• Peter Lucas, Professor emeritus at IST, TU Graz.
• Walther Neuper http://www.ist.tu-graz.ac.at/neuper/
• Tobias Nipkow http://www4.informatik.tu-muenchen.de/ nipkow/
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• Klaus Schmaranz http://www.iicm.edu/iicm/staff/university506a/kschmar
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