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## **FACULTY OF COMPUTER SCIENCE AND AUTOMATION**



## **COMPUTER SCIENCE MEETS AUTOMATION**

### **VOLUME I**

**Session 1 - Systems Engineering and Intelligent Systems**

**Session 2 - Advances in Control Theory and Control Engineering**

**Session 3 - Optimisation and Management of Complex  
Systems and Networked Systems**

**Session 4 - Intelligent Vehicles and Mobile Systems**

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## Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52<sup>nd</sup> International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.

I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.



Professor Peter Scharff  
Rector, TU Ilmenau



Professor Christoph Ament  
Head of Organisation



## Table of Contents



# CONTENTS

	Page
<b>1 Systems Engineering and Intelligent Systems</b>	
A. Yu. Nedelina, W. Fengler DIPLAN: Distributed Planner for Decision Support Systems	3
O. Sokolov, M. Wagenknecht, U. Gocht Multiagent Intelligent Diagnostics of Arising Faults	9
V. Nissen Management Applications of Fuzzy Control	15
O. G. Rudenko, A. A. Bessonov, P. Otto A Method for Information Coding in CMAC Networks	21
Ye. Bodyanskiy, P. Otto, I. Pliss, N. Teslenko Nonlinear process identification and modeling using general regression neuro-fuzzy network	27
Ye. Bodyanskiy, Ye. Gorshkov, V. Kolodyazhniy, P. Otto Evolving Network Based on Double Neo-Fuzzy Neurons	35
Ch. Wachten, Ch. Ament, C. Müller, H. Reinecke Modeling of a Laser Tracker System with Galvanometer Scanner	41
K. Lüttkopf, M. Abel, B. Eylert Statistics of the truck activity on German Motorways	47
K. Meissner, H. Hensel A 3D process information display to visualize complex process conditions in the process industry	53
F.-F. Steege, C. Martin, H.-M. Groß Recent Advances in the Estimation of Pointing Poses on Monocular Images for Human-Robot Interaction	59
A. González, H. Fernlund, J. Ekblad After Action Review by Comparison – an Approach to Automatically Evaluating Trainee Performance in Training Exercise	65
R. Suzuki, N. Fujiki, Y. Taru, N. Kobayashi, E. P. Hofer Internal Model Control for Assistive Devices in Rehabilitation Technology	71
D. Sommer, M. Golz Feature Reduction for Microsleep Detection	77

F. Müller, A. Wenzel, J. Wernstedt A new strategy for on-line Monitoring and Competence Assignment to Driver and Vehicle	83
V. Borikov Linear Parameter-Oriented Model of Microplasma Process in Electrolyte Solutions	89
A. Avshalumov, G. Filaretov Detection and Analysis of Impulse Point Sequences on Correlated Disturbance Phone	95
H. Salzwedel Complex Systems Design Automation in the Presence of Bounded and Statistical Uncertainties	101
G. J. Nalepa, I. Wojnicki Filling the Semantic Gaps in Systems Engineering	107
R. Knauf Compiling Experience into Knowledge	113
R. Knauf, S. Tsuruta, Y. Sakurai Toward Knowledge Engineering with Didactic Knowledge	119
<b>2 Advances in Control Theory and Control Engineering</b>	
U. Konigorski, A. López Output Coupling by Dynamic Output Feedback	129
H. Toossian Shandiz, A. Hajipoor Chaos in the Fractional Order Chua System and its Control	135
O. Katernoga, V. Popov, A. Potapovich, G. Davydau Methods for Stability Analysis of Nonlinear Control Systems with Time Delay for Application in Automatic Devices	141
J. Zimmermann, O. Sawodny Modelling and Control of a X-Y-Fine-Positioning Table	145
A. Winkler, J. Suchý Position Based Force Control of an Industrial Manipulator	151
E. Arnold, J. Neupert, O. Sawodny, K. Schneider Trajectory Tracking for Boom Cranes Based on Nonlinear Control and Optimal Trajectory Generation	157



K. Shaposhnikov, V. Astakhov The method of ortogonal projections in problems of the stationary magnetic field computation	165
J. Naumenko The computing of sinusoidal magnetic fields in presence of the surface with bounded conductivity	167
K. Bayramkulov, V. Astakhov The method of the boundary equations in problems of computing static and stationary fields on the topological graph	169
T. Kochubey, V. Astakhov The computation of magnetic field in the presence of ideal conductors using the Integral-differential equation of the first kind	171
M. Schneider, U. Lehmann, J. Krone, P. Langbein, Ch. Ament, P. Otto, U. Stark, J. Schrickel Artificial neural network for product-accompanied analysis and control	173
I. Jawish The Improvement of Traveling Responses of a Subway Train using Fuzzy Logic Techniques	179
Y. Gu, H. Su, J. Chu An Approach for Transforming Nonlinear System Modeled by the Feedforward Neural Networks to Discrete Uncertain Linear System	185
<b>3      Optimisation and Management of Complex Systems and Networked Systems</b>	
R. Franke, J. Doppelhammer Advanced model based control in the Industrial IT System 800xA	193
H. Gerbracht, P. Li, W. Hong An efficient optimization approach to optimal control of large-scale processes	199
T. N. Pham, B. Wutke Modifying the Bellman's dynamic programming to the solution of the discrete multi-criteria optimization problem under fuzziness in long-term planning	205
S. Ritter, P. Bretschneider Optimale Planung und Betriebsführung der Energieversorgung im liberalisierten Energiemarkt	211
P. Bretschneider, D. Westermann Intelligente Energiesysteme: Chancen und Potentiale von IuK-Technologien	217

Z. Lu, Y. Zhong, Yu. Wu, J. Wu WSReMS: A Novel WSDM-based System Resource Management Scheme	223
M. Heit, E. Jennenchen, V. Kruglyak, D. Westermann Simulation des Strommarktes unter Verwendung von Petrinetzen	229
O. Sauer, M. Ebel Engineering of production monitoring & control systems	237
C. Behn, K. Zimmermann Biologically inspired Locomotion Systems and Adaptive Control	245
J. W. Vervoorst, T. Kopfstedt Mission Planning for UAV Swarms	251
M. Kaufmann, G. Bretthauer Development and composition of control logic networks for distributed mechatronic systems in a heterogeneous architecture	257
T. Kopfstedt, J. W. Vervoorst Formation Control for Groups of Mobile Robots Using a Hierarchical Controller Structure	263
M. Abel, Th. Lohfelder Simulation of the Communication Behaviour of the German Toll System	269
P. Hilgers, Ch. Ament Control in Digital Sensor-Actuator-Networks	275
C. Saul, A. Mitschele-Thiel, A. Diab, M. Abd rabou Kalil A Survey of MAC Protocols in Wireless Sensor Networks	281
T. Rossbach, M. Götze, A. Schreiber, M. Eifart, W. Kattanek Wireless Sensor Networks at their Limits – Design Considerations and Prototype Experiments	287
Y. Zhong, J. Ma Ring Domain-Based Key Management in Wireless Sensor Network	293
V. Nissen Automatic Forecast Model Selection in SAP Business Information Warehouse under Noise Conditions	299
M. Kühn, F. Richter, H. Salzwedel Process simulation for significant efficiency gains in clinical departments – practical example of a cancer clinic	305

D. Westermann, M. Kratz, St. Kümmerling, P. Meyer Architektur eines Simulators für Energie-, Informations- und Kommunikationstechnologien	311
P. Moreno, D. Westermann, P. Müller, F. Büchner Einsatzoptimierung von dezentralen netzgekoppelten Stromerzeugungsanlagen (DEA) in Verteilnetzen durch Erhöhung des Automatisierungsgrades	317
M. Heit, S. Rozhenko, M. Kryvenka, D. Westermann Mathematische Bewertung von Engpass-Situationen in Transportnetzen elektrischer Energie mittels lastflussbasierter Auktion	331
M. Lemmel, M. Schnatmeyer RFID-Technology in Warehouse Logistics	339
V. Krugljak, M. Heit, D. Westermann Approaches for modelling power market: A Comparison.	345
St. Kümmerling, N. Döring, A. Friedemann, M. Kratz, D. Westermann Demand-Side-Management in Privathaushalten – Der eBox-Ansatz	351
<b>4      Intelligent Vehicles and Mobile Systems</b>	
A. P. Aguiar, R. Ghabchelloo, A. Pascoal, C. Silvestre , F. Vanni Coordinated Path following of Multiple Marine Vehicles: Theoretical Issues and Practical Constraints	359
R. Engel, J. Kalwa Robust Relative Positioning of Multiple Underwater Vehicles	365
M. Jacobi, T. Pfützenreuter, T. Glotzbach, M. Schneider A 3D Simulation and Visualisation Environment for Unmanned Vehicles in Underwater Scenarios	371
M. Schneider, M. Eichhorn, T. Glotzbach, P. Otto A High-Level Simulator for heterogeneous marine vehicle teams under real constraints	377
A. Zangrilli, A. Picini Unmanned Marine Vehicles working in cooperation: market trends and technological requirements	383
T. Glotzbach, P. Otto, M. Schneider, M. Marinov A Concept for Team-Orientated Mission Planning and Formal Language Verification for Heterogeneous Unmanned Vehicles	389

M. A. Arredondo, A. Cormack SeeTrack: Situation Awareness Tool for Heterogeneous Vehicles	395
J. C. Ferreira, P. B. Maia, A. Lucia, A. I. Zapaniotis Virtual Prototyping of an Innovative Urban Vehicle	401
A. Wenzel, A. Gehr, T. Glotzbach, F. Müller Superfour-in: An all-terrain wheelchair with monitoring possibilities to enhance the life quality of people with walking disability	407
Th. Krause, P. Protzel Verteiltes, dynamisches Antriebssystem zur Steuerung eines Luftschiffes	413
T. Behrmann, M. Lemmel Vehicle with pure electric hybrid energy storage system	419
Ch. Schröter, M. Höchemer, H.-M. Groß A Particle Filter for the Dynamic Window Approach to Mobile Robot Control	425
M. Schenderlein, K. Debes, A. Koenig, H.-M. Groß Appearance-based Visual Localisation in Outdoor Environments with an Omnidirectional Camera	431
G. Al Zeer, A. Nabout, B. Tibken Hindernsvermeidung für Mobile Roboter mittels Ausweichecken	437
<b>5      Robotics and Motion Systems</b>	
Ch. Schröter, H.-M. Groß Efficient Gridmaps for SLAM with Rao-Blackwellized Particle Filters	445
St. Müller, A. Scheidig, A. Ober, H.-M. Groß Making Mobile Robots Smarter by Probabilistic User Modeling and Tracking	451
A. Swerdlow, T. Machmer, K. Kroschel, A. Laubenheimer, S. Richter Opto-acoustical Scene Analysis for a Humanoid Robot	457
A. Ahranovich, S. Karpovich, K. Zimmermann Multicoordinate Positioning System Design and Simulation	463
A. Balkovoy, V. Cacenkin, G. Slivinskaia Statical and dynamical accuracy of direct drive servo systems	469
Y. Litvinov, S. Karpovich, A. Ahranovich The 6-DOF Spatial Parallel Mechanism Control System Computer Simulation	477

V. Lysenko, W. Mintchenya, K. Zimmermann 483  
Minimization of the number of actuators in legged robots using  
biological objects

J. Kroneis, T. Gastauer, S. Liu, B. Sauer 489  
Flexible modeling and vibration analysis of a parallel robot with  
numerical and analytical methods for the purpose of active vibration damping

A. Amthor, T. Hausotte, G. Jäger, P. Li 495  
Friction Modeling on Nanometerscale and Experimental Verification

**Paper submitted after copy deadline**

**2 Advances in Control Theory and Control Engineering**

V. Piwek, B. Kuhfuss, S. Allers 503  
Feed drivers – Synchronized Motion is leading to a process optimization



# Compiling Experience into Knowledge

## Abstract

TYPICAL application fields of Knowledge Based Systems are usually characterized by having human expertise as the only one source to specify their desired behavior. Therefore, their design, evaluation and refinement has to make effective use of this valuable source. After an introduction to the concept of collecting validation experience in a Validation Knowledge Base (VKB), the paper introduces an estimation of the significance of the cases collected in the VKB. A high significance signalizes that a VKB should not longer serve as a case-based source of external (outside the Knowledge Base) knowledge, but compiled into the Knowledge Base instead. Based on this significance estimation, a technology to compile well selected cases into the Knowledge Base of the system under evaluation is presented.

## 1 Introduction

The purpose of refinement approaches is to adjust a system according to new insights. Such insights may be uncovered by detecting invalidities when applying a validation technology, but also by gaining experience when considering cases. In particular, they aim at a knowledge base reconstruction so that the input–output behavior and, in some approaches, the complete rule trace is adapted to the new insights.

There is a history of attempts to face this problem for rule–based systems. A quite comprehensive digest about pros and cons of systems like TEIRESIAS [1], SEEK/SEEK2 [2, 4], the *Reduced Theory Learning System* RTLS [3] with a so–called relaxed retranslation that has been criticized in [13] and [16], and KRUSTWORKS [15], e.g., is provided in [5].

Besides particular individual drawbacks, these approaches share the property that they can't produce a rule base which is 100 % correct. Correctness, in this context, means correctness w.r.t. a set of test cases. Furthermore, they may cover some inherent anomalies and may not be interpretable by topical human experts.

AI systems' design and maintenance heavily depends on the quality of the human expertise and effectiveness of its involvement in the system's design, evaluation, and refinement. For their validation and refinement, the authors introduced a case based technology [6, 7].

To make validation results less dependent on the experts' opinions and to decrease the workload of the experts, the authors developed a concept to collect case oriented experience in a Validation Knowledge Base (VKB) [8, 10].

These concepts have been involved in a validation framework [7]. To estimate the usefulness of these concepts and to reveal their weaknesses, a prototype test was performed [9].

The VKB concept so far utilizes the external knowledge in a VKB as an additional source of knowledge for system validation. It is organized in a case-based manner. However, at some point a VKB should not longer serve as a case-based source of external (outside the Knowledge Base) knowledge, but compiled into the Knowledge Base instead. If a VKB content turns out to be accepted by topical experts, it should be utilized to refine the Knowledge Base to become a source of knowledge for the system itself, not just for its evaluation. Especially the cases, which gained a high agreement in the expert community

over a long period of time are worth to be included into the Knowledge Base. A technology to do so is introduced here.

The paper is organized as follows. Section two briefly introduces the VKB concept. In section three, the utilization of VKB for system refinement is outlined. Section four presents a technology to compile the cases of VKB into the rules of the Knowledge Base. The paper is finalized by a summary.

## 2 Collecting experience: The VKB approach so far

In spite of significant advances in recent years, validation of knowledge-based systems still requires significant involvement on the part of human validators. In contrast to verification, which seeks to assure compliance with specifications and the absence of specific errors without executing the system, validation typically involves rigorous and often extensive testing of the system.

The results of these tests are nearly always evaluated by expert validators who may not always agree among themselves. The size of the test case set, the frequency of the validation exercises and the number of expert validators required for each such exercise can combine to pose great burdens of time and effort on human expert validators. These expert validators are a scarce resource, have limited time, and are expensive to employ. These limitations have the potential to degrade a validation exercise.

Our concepts of a Validation Knowledge Base was originally proposed by TSURUTA et al. [14]. TSURUTA's work appears to be the first to specifically address the use of prior validation knowledge for improving the validation process. His work aimed at developing validation solutions for commercial applications, and he addresses this issue frequently [12].

Our work is implemented in the context of our previously described validation framework [7], which includes an expert validator review of test cases and results using a variation of a TURING Test for the validation of knowledge-based systems. In this step, humans play the role of expert validators as part of a validation panel. Their task is (1) to solve the test cases posed to the system under evaluation and (2) to review and provide their judgment on the correctness (the ratings) of all anonymous solutions (the system's as well as the panel's own).

To improve the validation process, the validation knowledge used in prior exercises, namely the set of test cases (the test inputs and the best rated solutions) along with their authors, must persist from one validation exercise to the next. This is effectively accomplished by the VKB.

The VKB and its historical validation knowledge can also significantly reduce the involvement of expert validators by eliminating their need to solve old test cases whose solutions are already found in the VKB. The expert validator panel needs only to solve new test cases created by the Validation Framework that are not already part of the VKB, because the VKB already have (formerly accepted) solutions available. However, they still have rate all solutions, because the former solution needs to be either confirmed or revised by the current expert panel to further "qualify" the VKB.

The VKB is a set of previous (historical) test cases and their best rated solutions, which can be described by 7-tuples  $[t_j, E_{Kj}, E_{Ij}, sol_{Kj}^{opt}, r_{IjK}, c_{IjK}, \tau]$ , in which

- $t_j$  is a test case input,
- $sol_{Kj}^{opt}$  is a solution associated to  $t_j$ , which gained the maximum experts' approval in a prior validation exercise,
- $E_{Kj}$  is the list of experts who provided this particular solution,



- $E_{I_j}$  is a list of experts who rated this solution,
- $r_{I_jK}$  is the rating of this solution, which is provided by the experts in  $E_I$ ,
- $c_{I_jK}$  is the certainty of this rating, and
- $\tau$  is a time stamp associated with the validation session in which the rating was provided.

Table 1 shows how the VKB would appear for a simple application. Here,  $e_1$ ,  $e_2$  and  $e_3$  are specific human expert validators. The outputs  $o_1, \dots, o_{25}$  are the test case outputs (solutions). The time stamps are denoted by natural numbers to indicate an unspecified time when the validation exercise was held in the right sequence.

The VKB is initially built as part of the first validation exercise. Here, each test case input used in the exercise, along with its optimal solution (as determined by the panel during that exercise), becomes a new entry. It is updated in subsequent validation exercises by adding all examined

Table 1: An example for *VKB*'s entries

$t_j$	$E_K$	$E_I$	$sol_{Kj}^{opt}$	$r_{ijk}$	$c_{ijk}$	$\tau_S$
$t_1$	$e_1, e_3$	$[e_1, e_2, e_3]$	$o_6$	$[1, 0, 1]$	$[0, 1, 1]$	1
$t_1$	$e_2$	$[e_1, e_2, e_3]$	$o_{17}$	$[0, 1, 0]$	$[1, 1, 1]$	4
$t_2$	$e_1, e_3$	$[e_1, e_2, e_3]$	$o_7$	$[0, 0, 1]$	$[0, 0, 1]$	1

test cases of this session. New entries, however, do not supersede old entries. Instead, the 'updated information' is represented by the new entries with a more recent time stamp.

The VKB functions in the second step, the test case experimentation. In the original approach, the test case generation procedure consists of two steps (1) generating a quasi exhaustive set of test cases *QuEST* and (2) reducing it down to a reasonably sized set of test cases *ReST* [7]. A test case is a pair  $[TestData, Solution]$ . Both *QuEST* and *ReST* are sets of such pairs. Exactly between these two sub-steps is the entry-point of the external validation knowledge stored in a VKB that has been constructed in prior validation sessions.

Both *QuEST* and the historical cases in VKB are subjected to the criteria-based reduction procedure that aims to build a subset of test cases in *QuEST* or VKB. The cases in VKB are included in the reduction process to (1) ensure that they meet the requirements of the current application and (2) their number is small enough to be the subject of the time consuming and expensive test case experimentation.

The VKB, therefore is a database of test cases and their associated solutions that received an optimal rating in previous validation sessions. These solutions are considered an additional (external) source of expertise that did not explicitly appear in the solving session, but it is a subject of the rating session.

Regardless of their former ratings, the cases originated from the VKB have to be rated by the current expert panel in the current session.

The set of solutions  $ExtSol \subseteq \Pi_2(ReST)$ , which are contributed by the VKB and which are subject of the rating process, is<sup>1</sup>

$$ExtSol := \{sol : \exists Entry : Entry \in VKB, \Pi_1(Entry) \in \Pi_1(ReST), sol = \Pi_4(Entry)\}$$

Because the criteria-based reduction process is controlled by a predetermined number  $m$  of cases that form the *ReST*, the **workload reduction factor** for the test case solving process for the expert validators can be quantified by the cardinality of *ExtSol* divided by the cardinality of *ReST*: *workload reduction factor* =  $\frac{|ExtSol|}{|ReST|}$

<sup>1</sup> $\Pi_i$  is the projection of the  $i$ -th element, i.e.  $\Pi_i(T)$  with  $T$  being a tuple denotes the  $i$ -th element of the tuple and  $\Pi_i(M)$  with  $M$  being a set of tuples denotes the set of  $i$ -th elements of the tuples in  $M$ .

The best rated solutions associated with the test cases in the VKB represent an additional (external) source of expertise. It is different from both the current expert validators' and the system's knowledge. The **expertise gain factor** introduced by the VKB is:  $expertise\ gain\ factor = \frac{|ReST|}{(|ReST|-|ExtSol|)}$

The usefulness of the VKB approach could be proven by an experiment with human experts. Starting with an initial rule base, validation sessions as described in [6] and [7] have been performed and a VKB has been built. [11] and [9] could impressively show the VKB's contribution to the validation knowledge in this experimental case study.

### 3 Evaluating experience: Estimating its significance by a metrics

In case the VKB contains cases with (1) an optimal solution that is different from the system's solution and (2) a certain significance that the optimal solution in VKB is correct, a system refinement based on the VKB's content is indicated.

Depending on the particular application, a minimum number  $n^{min}$  of entries for a test case input  $t_j$  and a minimum significance level  $0 \ll sig^{min} \leq 1$  needs to be determined.

Indications for the correctness of an optimal solution  $sol_{Kj}^{opt}$  to a case input  $t_j$  in VKB are high values of the following metrics

- approval rate  $app = \frac{\# \text{ of positive ratings } r_{ijk} = 1}{\text{total } \# \text{ of ratings to } t_j}$
- persistence rate  $per = \frac{\# \text{ of entries for } t_j \text{ with } sol_{Kj}^{opt}}{\text{total } \# \text{ of entries to } t_j}$
- agreement rate  $agr = \frac{\# \text{ of experts providing } r_{ijk} = 1}{\text{total } \# \text{ of experts providing a } r_{ijk}}$

In case (1) the minimum number  $n^{min}$  of entries for a test case input  $t_j$  is reached and (2) all three of the above rates exceed the minimum significance level  $sig^{min}$ , the pair  $[t_j, sol_{Kj}^{opt}]$  is worth to be compiled into the Knowledge Base as its input/output behavior for  $t_j$ . This is performed by a technology similar to the refinement technology introduced in [7] and described in the following section.

After compiling a case into the Knowledge Base, its usage as a validation test case becomes obsolete. Therefore, the related entries in VKB need to be removed.

### 4 Utilizing experience: Compiling it into knowledge

The refinement procedure looks for rule chains of cases in the VKB, which have a different solution in VKB than the rule chain ends up with. It starts with the last rule in this chain and analyses *all* VKB cases using this rule. It systematically constructs new rules as a substitute of it, which map the cases that have a different solution to this different solution and keeps the mapping of all other cases (at all, not only those in VKB) as it was before the refinement. So it is pretty "conservative", because it changes the I/O behavior of the rule as few as possible, i.e. exclusively for cases that are shown to be solved wrong by the rule base. The technique is applicable to rule bases as introduced in [7] and consists of the following steps.

**Identifying "Guilty Rules"** If the last rule  $r_l$  in the rule trace for a case input  $t_j \in \Pi_{inp}(T)$  infers a solution different from  $sol_{Kj}^{opt} \in \Pi_{outp}(T)$ , this rule  $r_l$  is "guilty" and therefore, subject of the following refinement technology. Let  $T_l \subseteq T$  be the set of cases that have  $r_l$  as their last rule in the rule traces for the cases in  $T$ .

Table 2: Reduction rules to construct substitutes for an invalid rule

<b>R1</b>	<p><math>pos \in Pos</math>, <math>s_{pos}</math> has a value set with no <math>\leq</math> relation, <math>\{s_{pos}^1, \dots, s_{pos}^m\}</math> are the values of <math>s_{pos}</math> occurring in <math>T_l^s</math></p> <div style="border: 1px solid black; padding: 5px; margin: 5px 0;"> <math>[T_l^s, Pos, \{p_1, \dots, p_n\}]</math> <span style="float: right;"><math>\hookrightarrow</math></span> </div> <p><b>1.</b> <math>[T_l^{s,1} \setminus \{[t_j, sol_s] \in T_l^s : s_{pos} \neq s_{pos}^1\}, Pos \setminus \{pos\}, \bigcup_{i=1}^m p_i \cup \{(s_{pos} = s_{pos}^1)\}]</math>  <math>\dots</math></p> <p><b>m.</b> <math>[T_l^{s,m} \setminus \{[t_j, sol_s] \in T_l^s : s_{pos} \neq s_{pos}^m\}, Pos \setminus \{pos\}, \bigcup_{i=1}^m p_i \cup \{(s_{pos} = s_{pos}^m)\}]</math></p>
Continue with each $T_l^{s,i}$ ( $1 \leq i \leq m$ ) separately.	
<b>R2</b>	<p><math>pos \in Pos</math>, <math>s_{pos}</math> has a value set with a <math>\leq</math>-relation, <math>s_{pos}^{min}</math> / <math>s_{pos}^{max}</math> are the smallest / largest value of <math>s_{pos}</math> within <math>T_l^s</math></p> <div style="border: 1px solid black; padding: 5px; margin: 5px 0;"> <math>[T_l^s, Pos, \{p_1, \dots, p_n\}]</math> <span style="float: right;"><math>\hookrightarrow</math></span> <math>[T_l^s, Pos \setminus \{pos\}, \bigcup_{i=1}^m p_i \cup \{(s_{pos} \geq s_{pos}^{min}), (s_{pos} \leq s_{pos}^{max})\}] \cup S_{excl}</math> </div> <p><math>S_{excl}</math> is the set of excluded values for <math>s_{pos}</math>, which have to be mapped to a solution different from <math>sol_s</math> because of belonging to some other <math>T_u^v</math> with <math>v \neq s</math>: <math>S_{excl} = \{(s_{pos} \neq s_{pos}^j) : \exists [t_j, sol_s] \in T_l^s \exists [t_m, sol_v] \in T_u^v (v \neq s) \text{ with } \forall p \neq pos : s_p^j = s_p^m, s_{pos}^{min} &lt; s_{pos}^m &lt; s_{pos}^{max}\}</math></p>

**Simple Refinement by Conclusion Replacement** If all cases  $t_j \in T_l$  have the same solution  $sol_{Kj}^{opt}$ , in rule  $r_l$  the conclusion part is substituted by  $sol_{Kj}^{opt}$ .

**Reconstructing the Remaining Guilty Rules** The remaining guilty rules are used by a set of cases  $T_l$ , which have different optimal solutions. The subsets with the same optimal solution are considered separately:

1.  $T_l$  of the rule  $r_l$  is split into subsets  $T_l^s$  ( $1 \leq s \leq n$ ) according to the  $n$  different solutions  $sol_{Kj}^{opt,1}, \dots, sol_{Kj}^{opt,n}$  for the cases  $t_j \in T_l$ .

The if-part(s) of the new rule(s) that substitute  $r_l$  are expressions  $e_i \in E$  of a set of  $p$  new alternative rules  $\{r_l^1, r_l^2, \dots, r_l^p\}$  for each  $T_l^s$  and will be noted as a set of sets  $P_l^s = \{\{e_1^1, \dots, e_{p_1}^1\}, \dots, \{e_1^p, \dots, e_{p_p}^p\}\}$ . The corresponding rule set of  $P_l^s$  is

$$r_l^1 : \bigwedge_{i=1}^{p_1} e_i^1 \rightarrow sol_s \quad \dots \quad r_l^p : \bigwedge_{i=1}^{p_p} e_i^p \rightarrow sol_s$$

2.  $Pos$  is the set of Positions (dimensions of the input space), at which the input data  $t_j \in \Pi_{inp}(T_l^s)$  of the test cases  $t_j \in T_l^s$  are not identical.

The generation of the  $p$  different if-parts in  $P_l^s$  is managed by a formal *reduction system*, which is applied to triples  $[T_l^s, Pos, P_l^s]$  until  $Pos$  becomes the empty set  $\emptyset$ .

3. The initial situation is  $[T_l^s, Pos, P_l^s]$  with  $P_l^s = \{\{(s_1 = s_1^{ident}), \dots, (s_q = s_q^{ident})\}\}$   
 $s_1, \dots, s_q$  are those positions, at which all test data  $t_j \in \Pi_{inp}(T_l^s)$  have the same value  $s_i^{ident}$ . Initially,  $P_l^s$  stands for just one rule:  $r_l^1 : \bigwedge_{i=1}^q (s_i = s_i^{ident}) \rightarrow sol_{Kj}^{opt,s}$
4. The reduction terminates with the situation  $[T_l^s, \emptyset, P_l^s]$ .

Table 2 shows the reduction rules applied to the triples. In [7] it is shown, that the reduction system is terminating, complete, and correct.

**Recompiling the constructed rules** The new rules generated so far are “one-shot-rules”, i.e. they infer directly from a system’s input to a system’s output. These rules might be difficult to read, because they may have very long *if*-parts, and difficult to interpret by subject matter experts. This problem can be defused by introducing the intermediate hypotheses into the computed new rules.

## 5 Summary

The formerly developed concept of a Validation Knowledge Base (VKB) was intended to model collective best experience of several human experts. The VKB is constructed and maintained across various validation exercises. If the knowledge gained in a VKB turns out to be well accepted by the expert community over a long period of time, this knowledge is worth to be compiled into the system’s Knowledge Base. This way, the knowledge dedicated to evaluate a system shifts to knowledge used to improve the system. Therefore, the paper introduced a technology to compile the case based knowledge of a VKB into the rule based knowledge of the system’s Knowledge Base.

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