Remembering Chandra Kintala

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With this contribution we would like to remember Chandra M. R. Kintala who passed away in November 2009. We will give short overviews of his CV and his contributions to the field of theoretical and applied computer science and, given the opportunity, will attempt to present the current state of limited nondeterminism and limited resources for machines. Finally, we will briefly touch on some research topics which hopefully will be addressed in the not so distant future.

1 Introduction

On November 05, 2009, Chandra M. R. Kintala passed away at the age of 61, suddenly and unexpectedly.

In this preliminary presentation and in a somewhat narrative, considerably more conceptual and less technical style, we would like to remember him as a person, as a researcher and as a promoter and co-founder of descriptional complexity, the IFIP Working Group 1.2 and the workshops DCAGRS and DCFS. An extended, more comprehensive version in the usual scientific style will follow.

Section 2 will briefly review Chandra’s CV. In Section 3, we will focus on his direct scientific contributions to the area of limited resources and descriptional complexity, and in Section 4, we will continue with research areas and results which can be considered direct or indirect spin-offs of his own research or which at least he promoted or which in their basic tenor resemble the flavor of his own approach to the area. Given this opportunity, we will attempt to present an overview of the current state of the area of limited nondeterminism and limited resources for machines. In Section 5, we will give a brief survey of the many contributions Chandra made to the area of applied computer science and of some basic ideas for questions which in his mind theoreticians could formulate and investigate. Section 6 will purposely be of a somewhat speculative nature in that we will list some topics and general, but not specific and by no means well-defined, questions which in very recent discussions with him shortly before his death emanated as interesting and hopefully promising topics from the vantage point of descriptional complexity. We should conclude this introduction with the following disclaimer: Largely due to his continuous interaction with applied computer science, Chandra’s view of limited resources and descriptional complexity was primarily influenced by a machine-based vantage point. For this reason and for the reason that we have to limit the scope of this contribution, we are taking a machine-based perspective and would like to apologize to everybody who otherwise should and would have been mentioned and cited.
2 Chandra’s CV

Chandra Mohan Rao Kintala was born on July 22, 1948, in the city of Berhampur in the state of Orissa, a regional but sleepy hub on India’s Eastern seaboard. He lost his father in his early teens, which made him face the reality of life quite early and which had a formative influence on him, both as a person and as a scientist. As a person in the sense that he always felt strong responsibility for everything he did and for the people who depended on him privately and professionally. As a scientist in the sense that, although he loved theoretical work, he never lost sight for the so-called more practical aspects and problems of computer science. He always saw theoretical and applied computer science as a unit, as two sides of the same coin. His “credo” can be summarized as follows: Theory should never lose sight of the practical questions and problems, and applied scientists should never stop explaining their problems to theoreticians and listen to what they have to say and offer. We will get back to this later.

He received his Bachelor’s Degree from Rourkela Engineering College and his Master’s from IIT Kanpur. In 1973 he decided to continue his education in North America, first joined the PhD program at the University of Waterloo and then went with his advisor Patrick Fischer to the Pennsylvania State University in 1974 when Pat Fischer became Department Head there. In 1977 he received his PhD degree from Penn State with a thesis on limited nondeterminism of Turing Machines.

In 1977 he joined the University of Southern California as an Assistant Professor and worked with Seymour Ginsburg on Grammar Forms and with Ron Book, who was then at UC Santa Barbara, on questions in Formal Languages.

He married in 1978 and lived with his wife Bharati in Santa Monica, where their daughter Sreelata was born, until 1980. As much as Chandra enjoyed life there, professionally and privately, he missed a close interaction with the more practical side of computer science. So when the opportunity arose to join Bell Labs in Murray Hill, he immediately saw this as a chance and moved to New Jersey in 1980, where a few years later his son Kumar was born. Those years were, in his own words, among the happiest years of his life, as the research culture at Bell Labs provided exactly the close and stimulating interaction between theory and applications that he had always been looking for. And since he always liked teaching, he also taught courses at Steven’s Institute of Technology in New Jersey, first as an Adjunct Professor and later as a Distinguished Industry Professor.

When Avaya Labs spun off from Bell Labs, he became Vice President of the Research Realization Center of Avaya Labs Research in Basking Ridge, New Jersey, where he continued the work he had begun at Bell Labs.

Although life, in his own words, was good to him, he faced the nagging question whether he should go back to his roots in India for at least a few years and how much he would still be able to blend in with the Indian culture and society. So, in Sept 2006, he went to Bangalore, India, to be the Director of Motorola Labs for two years and then joined Yahoo Labs for one year. There he was responsible for research in mobile communications, system sciences and for academic relations with top technical institutes in India. But during those three years he realized that he missed his two kids, who had stayed in the US, too much and that his real home had become New Jersey. So he moved back to the US and, in August 2009, joined the New Jersey Institute of Technology as Professor and Director of Software Engineering in its Computer Science Department.

In the late summer of 2009, only two months before his unexpected death, we had extensive talks with him. He was still full of ideas and had specific plans to investigate in a theoretical setting many of the practical computer science problems which he had run across during his time in industry. We will report on some of these ideas below in Sections 5 and 6.

We would not do justice to the footprint which Chandra left on our community if we did not mention...
the instrumental role he played with others in founding the DCAGRS workshop, which later turned into our current DCFS workshop. During his time at Bell Labs and later at Avaya Labs, Chandra became more and more involved with the problem of software reliability. And while the standard concept of software reliability often meant that software should run correctly and should only make as few mistakes as possible, together with others he promoted the notion that correct and reliable software would also entail easily understandable and succinct descriptions of low descriptional complexity, where “low” would always have to be defined within the respective applicable setting. So in 1998, together with others, he founded the workshop FDSR (Formal Descriptions and Software Reliability) as a satellite workshop to ISSRE (International Symposium on Software Reliability Engineering). As Jürgen Dassow pointed out at DCFS 2009 in Magdeburg, FDSR was essentially the beginning of our DCFS community and led to the first DCAGRS-DCFS workshop in Magdeburg in 1999, as it was realized that descriptional complexity would be better off having its own focus, forum and workshop. Finally we should mention that he acted as Vice-Chair of our parent organization, the IFIP Working Group 1.2 for Descriptional Complexity, and took over as Chair when the position of Chair became vacant.

3 Chandra’s contributions to the area of theoretical computer science

Until the mid-seventies nondeterminism was, with a few exceptions, essentially viewed as a non-measurable or non-scalable resource. Either a machine was nondeterministic or it was not. Since early on Chandra saw theoretical computer science also through the prism of applied computer science, he realized that in practical models you often don’t need the full or unlimited power of nondeterminism. A little amount of guessing is often all you need. Also, from a theoretical point, nondeterminism was at least for some automata classes such a powerful resource (some questions became computationally much more complex and in some instances even undecidable, when allowing full nondeterminism) that making nondeterminism a measurable and scalable resource should enable us to get a better handle on nondeterminism in general. So, in his PhD thesis and follow-up papers the concept of limited nondeterminism was introduced and investigated for Turing Machine computations [12, 39, 40].

When Albert Meyer from MIT visited Penn State in 1975 and gave an inspiring talk on his and Michael Fischer’s seminal paper on the economy of description [66], it led to combining the concept of limited nondeterminism and limited resources with the concept of succinct descriptions, which was applied first to context-free languages in [36]. The concept of limited nondeterminism was then applied to finite automata in [42], where it was shown that there is an infinite hierarchy of finite amounts of nondeterminism generating an infinite hierarchy of trade-offs between NFAs and DFAs.

A particular way of limiting nondeterminism by weighing the various choices a machine can make and the resulting trade-offs to (unweighed) nondeterminism were investigated in the following papers on stochastic automata [41, 43].

Usually, when trying to show maximal trade-offs between (finite state) machines of different degrees of nondeterminism, we construct specific witness languages which cause a particular trade-off, and these languages change as the particular trade-offs change that we want to achieve. In [19] the concept of (nondeterminism)-spectra of regular languages was introduced in order to measure the inherent nondeterminism of regular languages. The spectrum of a regular language is an infinite vector whose ith position lists the smallest number of states which any NFA with nondeterminism-degree i needs to accept this language. As might be expected, there are regular languages which are very resilient to finite nondeterminism so that any finite amount of nondeterminism does not suffice and where an infinite amount of nondeterminism is needed to yield a reduction in the number of states. And there are regular
languages which are inherently very nondeterministic in the sense that every increase in the number of choices yields a reduction in the number of states until the smallest NFA has been obtained.

4 Current state of the area of limited nondeterminism and limited resources for machines

Since its early days, the area of limited nondeterminism and limited resources for machines has come a long way, and although many of the papers published in this area since then have not been influenced by Chandra’s work directly or indirectly, they resemble the flavor of his own approach to the area and are part of an area which, together with others, he started and promoted for many years. So we would like to take this opportunity and attempt to give an overview of the current state of this area. And again, as already done in the introduction, we would like to apologize for only looking at the machine-based perspective. Also, since even within this machine-based perspective alone the number of papers has become so enormous and since, due to space considerations, we have to limit the bibliography, we would like to refer the reader to [11,18] for additional references. If, nevertheless, we unintentionally might have overlooked a paper here or there which should have been included, please accept our apologies again. Moreover, since in this workshop contribution we want to remember Chandra, the person as well as the theoretical and applied scientist, this section will consist essentially only of a listing of the many and varied contributions to this area to date. In some cases, strictly on a random basis and not emphasizing one area over another, we will include a few additional comments. A more detailed survey will have to be deferred to the extended version.

Limiting the full power of NFAs by considering subclasses of regular languages was studied for finite languages in [63,75], for subregular languages in [3], and for unary languages in [9,10,65]. The relationship between (limited) ambiguity and the size of NFAs was extensively treated in [20,26,53,54,55,56,71,77]. A somewhat different approach to limiting (or extending) nondeterminism by allowing multiple initial states (in DFAs and NFAs) was investigated in [16,24,32,80].

Measuring nondeterminism based on communication complexity methods was dealt with in [25].

The influence of nondeterminism and ambiguity on the size of Büchi automata was looked at in [68].

Turning to PDAs, non-recursive trade-offs were shown between unambiguous and deterministic PDAs in [79] and between ambiguous and unambiguous PDAs in [76]. The concept of limited nondeterminism for PDAs was investigated in [21,22,23,67,72,73,74,81], while limited ambiguity of PDAs or CFGs was studied in [22,23,83,84,85].

Limiting the number of turns in successful computations of PDAs yields a hierarchy of non-recursive trade-offs with respect to the number of turns [60]. These non-recursive trade-offs become “only” exponential and thus recursive, when bounded languages are studied [62].

The limitations of nondeterminism mentioned so far concern the total amount of nondeterminism applied, regardless of when the nondeterminism occurs. When dealing with valuable and powerful resources it is often essential to use the resources not only economically but also in the right situation and context or under appropriate conditions. This context-dependent use of nondeterminism was investigated for PDAs in [48,52,64], whereas the context-dependent control of stack-turns in PDAs was studied in [49].

Limited resources for Turing Machines were investigated in [8,17,44,46,47].

The effect of limiting resources on the computational capacity and the consequences for the descriptive complexity were also investigated for the parallel model of cellular automata. For example, limited nondeterminism was considered in [4,6,7] and time hierarchies were refined in [5,30]. Recently, lim-
iterations on the number of cells \[59, 61\] as well as on the amount of communication between the cells were studied in \[50, 51\].

Finally, turning to parsers, in \[15\] an exponential trade-off was shown between arbitrary deterministic parsers, which are allowed to detect an error arbitrarily late, and correct-prefix-parsers, which have to detect an error as early as possible. A “limited approach” to this trade-off was taken in \[13\] by introducing and investigating various delay-spectra where the parsers become gradually smaller as the maximal delay in recognizing an error slowly increases. And finally looking at parsers for LL\((k)\) and LR\((k)\) languages, the effect on the parser-size by gradually increasing or decreasing the look-ahead was studied in \[1, 2, 57\].

5 Chandra’s contributions to the area of applied computer science

Summarizing Chandra’s almost 30 years of highly successful research and management in industry is beyond the scope of this paper. In his own words taken from Chandra’s Website at NJIT, “Some of the noteworthy accomplishments (...) are

- a language and a software tool now called “Backtalk” with Dr. David Belanger in 80s; it is still used in AT&T for data analytics on very large databases,
- concepts and the components for Software-implemented Fault Tolerance and Software Rejuvenation with Dr. Yennun Huang in early 90s; they are now widely used in industry and academia,
- a Layer 7 network switch based on Linux for web content distribution in his department in late 90s; it led to a new business group in Lucent, and
- an enterprise network monitoring system called Expertnet in early 2000s; it is still a key component in several products and services from Avaya.”

Here, we will now focus on one select topic in which Chandra was particularly active, namely Software Fault Tolerance. Please note that for space reasons we decided to not include a detailed bibliography for Chandra’s applied work. Therefore we will also limit the references for Software Fault Tolerance to some exemplary pointers only.

Chandra was a member of IFIP WG 10.4 on Dependable Computing and served as Program Committee Member for Conferences such as ISSRE (International Symposium on Software Reliability Engineering) and DSN (Dependable Systems and Networks) for which he also was General Chair in 2006. According to Chandra’s definition, Software Fault Tolerance is “a set of software components executing in the application layer of a computer system to detect and recover from faults that are not handled in the underlying hardware or operating system layers” \[28\].

Software Fault Tolerance is an essential feature as more and more mission-critical tasks in enterprises are depending on the availability of services provided by IT systems. If a critical application crashes or hangs, the consequences can be severe. Such a software failure can have a number of reasons ranging from application software faults to operating system software faults to faults in the underlying hardware. Many faults are transient, i.e., “the failure may not recur if the software is reexecuted on the same input” \[28\]. For example, consider a client/server application hanging because of network-related issues or a failing application on a server due to an unusual sequence of requests.

One of Chandra’s most successful projects was SwiFT, Software Implemented Fault Tolerance \[27\]. SwiFT used technologies such as checkpointing and message logging \[82\]. These terms denote saving the state of a process onto a second machine or to storage at certain intervals. In case of a fault, the process is stopped and recovered by loading the last checkpointed state and replaying the logged messages since
then. The failure of a process is detected by a watchdog daemon process which either periodically sends a signal to the application process and waits for a response or receives heartbeat messages from it. If the communication fails, the daemon waits for a certain period and then retries. If the retry is also unsuccessful, it is assumed that the application is hung and recovery is initiated. Under Chandra’s supervision, such services were successfully implemented for Unix and Windows NT [58] and are used in commercial products.

Furthermore, some components of SwiFT were extended to support software rejuvenation, “the concept of gracefully terminating an application and immediately restarting it in a clean state” [29] in order to counter process aging due to, e.g., memory and/or file descriptor leaks. Software rejuvenation can be beneficial in a variety of scenarios, see for instance [14] or [38].

Clearly, the question whether a process is hung or not is undecidable in the Turing sense. Therefore, more theoretically oriented approaches and models for software reliability are based on other approaches such as, e.g., statistical models like Markov Chains. While Formal Languages and Automata Theory played virtually no role in Software Fault Tolerance, Chandra saw connections between these fields and hoped that, if the communities worked closer together, Formal Languages and Automata could provide valuable contributions to software reliability.

The question arises whether existing results on restarting automata [31, 69, 70] can be interpreted as a theoretical model for or answer to the concept of rejuvenation or whether restarting automata can be extended to model the concept of rejuvenation by, e.g., allowing the automata, based on a certain strategy, to store states of the computation which can be returned to when “needed” and from which the computation could resume.

Due to the complexity of large software systems and the cost involved in building them, it is a common practice to use reusable commercial off-the-shelf software components as building blocks. In [34], Chandra and others presented a model for such systems based on communicating finite state machines and showed that the reliability of such a system cannot be precisely or approximately calculated even if the reliability of the individual components is known. From a theoretical perspective (and with Rice’s Theorem in mind), the result might not seem surprising. However, Chandra considered this paper as a first step to convince the software reliability community of the usefulness and applicability of formal languages and automata to problems in software reliability.

Chandra envisioned that studying the descriptional complexity of new models tailored specifically at software reliability could significantly advance our theoretical knowledge in this area. His paper [33] augmented his efforts to convince the applied community of formal language models with an approach to inspire the theoretical community to take a closer look at software reliability in order to come up with new models of interest to both the applied and the theoretical community. In his own words, “In order to start research relating descriptional complexity and software reliability, first and foremost, models for software systems need to be found and (possibly different) measures for their “simplicity” and their “reliability” have to be identified” [33].

In this work, Chandra used finite automata as models for software systems and studied trade-offs between reliability and conciseness of such systems against an intended system behavior specified by a formal language. “A software system can be considered a Turing Machine that processes a given input and produces some output. Taking the abstraction one step further, a finite automaton can be interpreted as strongly restricted version of a Turing Machine. By restricting the output to “yes” or “no” only, the set of all accepted inputs turns into a formal language and, along the same lines, the expected behavior of the software system also becomes a formal language. Much as the reliability of a software system needs to be evaluated against its required functions, its specification, the reliability of our model of the system, the DFA, needs to be evaluated against a language specifying the intended system behavior” [33].
Intuitively, the reliability of a finite automaton used as description for the given specification is high if the difference between it and the language accepted by the automaton is small. The presented results included that the savings in the number of states between a fully reliable and a less reliable representation cannot be bounded by any function, even if the unreliable descriptions are required to exceed any given fixed level of reliability. Moreover, [33] shows that, for a single regular language, there is a level of reliability such that any description exceeding this level is at least as big as the smallest DFA for the language. The quantitative measures in [33] were later augmented by qualitative measures for the reliability of Finite Automata in [35].

After returning to academia, Chandra had planned to resume his work to bring experts from both communities together. One of the main obstacles, in his view, was that problems of immense practical interest often turn out to be intractable in theoretical models. While a mathematical proof for, e.g., the undecidability of a problem in a given model is a satisfactory and meaningful result for a theoretician, a practitioner cannot simply put up with it. Even if the problem is intractable, if it is relevant, it needs to be solved in one way or another.

One of the ideas to cope with this situation is to start with simple yet tractable models (such as Finite Automata) and then extend the models towards more realistic scenarios while maintaining tractability. Clearly, such a research project would require experts from the applied as well as the theoretical community. With his premature death, the task to pick up these ideas is now left to others.

6 Some possible future topics for descriptional complexity and limited resources

Since with this contribution we are remembering Chandra Kintala, we would like to list some ideas and “visions” for possible future topics in the area of descriptional complexity and limited resources. These ideas are the result of discussions we had with him in the late Summer of 2009 when he had returned to New Jersey and, after 30 years in industry, had in his own words rediscovered his love and excitement for academia and theoretical computer science in general and descriptional complexity in particular. The ideas we are going to list below are of a “visionary” and speculative nature, are not (and cannot be yet) well-formulated or well-defined questions, are by no means fully thought through, might contain many pitfalls or completely intractable hurdles, and they might actually be controversial in the sense whether one should move in this direction at all. In other words, these ideas ought to be taken as suggestions for topics and not as well-formulated research questions. And, as mentioned above, all this can only be very sketchy here and by no means complete.

As intriguing, fascinating and often difficult (to prove) non-recursive trade-offs are, from the perspective of an applied computer scientist they are not very useful, except for the insight that one might step onto dangerous territory. For, as much as one is interested in maximal compressions, these compressions should still contain enough information to algorithmically restore descriptions to their original state. In other words, our non-recursive hierarchies, e.g., when increasing the degree of nondeterminism or ambiguity or the number of turns in PDAs, are still too coarse. This might be caused by the fact that we are considering PDAs where the stack heights, or even more so, the stack contents of the various computations for an input are not “structurally” related, e.g., not related by a recursive function. Let us bear in mind that for accepting the invalid computations of a Turing Machine we use nondeterministic PDAs where the different computations on a given input show “opposite” stack behavior. What effect on the trade-offs in descriptional complexity would a restriction have that requires the stack-contents or stack heights to be structurally or functionally related by some recursive function? Would we then get i-
finite recursive hierarchies of trade-offs which are based on the recursive functions or structural relations used? Would such restrictions be useful from an applied perspective? Probably more than non-recursive trade-offs?

When we prove (infinite hierarchies of) non-recursive trade-offs, we usually use witness languages which account for a specific jump from one level to the next within those hierarchies. Again, as enlightening as this might be from a theoretical vantage point, it is not exactly what applied computer scientists are confronted with. They are normally faced with a specific language which to elegantly describe they have several tools (resources) of varying degrees at their disposal. So questions arise like: How much of a certain resource can or should one apply in order to get the description down to a reasonable size, if that is at all possible? Does the spectrum of the language (cf. [19]) generated by ever increasing amounts of a certain resource show a “steady decline” in size or does it remain constant up to a point from which on it collapses “dramatically”? These ideas lead us to suggest to investigate, e.g., for context-free languages, ambiguity-spectra, nondeterminism-spectra, turn-spectra, state-spectra and other spectra of limited resources.

In his practical work, Chandra often had to work with attribute grammars, e.g. [37], which were introduced by Knuth [45] in order to obtain elegant context-free descriptions, e.g., of binary numbers. These grammars work with inherited and synthesized attributes, and often small or elegant descriptions can be obtained by carefully balancing the interaction of these different kinds of attributes. What happens to the size of the grammar when we gradually shift away from the optimal balance by limiting the resource of inherited attributes in favor of synthesized attributes or vice versa? A first step in this direction was undertaken in [78].

The above list of possible topics is only a sample list of topics which lie at the juncture of applied computer science and descriptive complexity and reflect Chandra’s view of our field. More on all this in an extended version.

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