Distributed Computing Column 56
Annual Review 2014

Jennifer L. Welch
Department of Computer Science and Engineering
Texas A&M University, College Station, TX 77843-3112, USA
welch@cse.tamu.edu

As with prior December issues, this issue is devoted to a review of notable events related to distributed computing that occurred during the year.

First, congratulations to Leslie Lamport for receiving the 2013 Turing Award! The award was announced in spring of 2014, and Leslie chose to give his acceptance lecture at PODC[1] 2014. The award was given

> "[f]or fundamental contributions to the theory and practice of distributed and concurrent systems, notably the invention of concepts such as causality and logical clocks, safety and liveness, replicated state machines, and sequential consistency."

More details, including photos, are in this column's PODC review. And a lengthy description of Leslie's many research accomplishments, authored by Dahlia Malkhi with contributions from several others, can be viewed here: `http://amturing.acm.org/award_winners/lamport_1205376.cfm`.

Also, congratulations to Kanianthra Mani Chandy and Leslie Lamport who received the 2014 Dijkstra Prize for their paper "Distributed Snapshots: Determining Global States of Distributed Systems"! The prize is jointly sponsored by ACM and EATCS, and is given alternately at PODC and DISC[2]; however, with Leslie speaking at PODC and Mani giving a keynote talk at DISC, and both of them alluding to the Dijkstra Prize, it was difficult to determine the official locale for the prize acceptance (officially it was given at PODC). The full citation can be found at `http://www.podc.org/dijkstra/2014-dijkstra-prize/`; highlights are:

> "The solution provided by Chandy and Lamport is extremely elegant and also remarkably simple... The paper provides the first clear understanding of the definition of

[1] ACM Symposium on Principles of Distributed Computing
[2] International Symposium on Distributed Computing

consistent global states in distributed systems. Consistent global states form the cornerstone of asynchronous distributed execution observation, and subsequent concepts such as those of the hugely popular vector clocks and concurrent common knowledge are based on consistent global states... [The paper] has had a profound and lasting impact on the theory and implementation of distributed algorithms and systems. It has led to concepts such as vector time, isomorphism of executions, global predicate detection, and concurrent common knowledge. Applications of the results of observing the system in consistent states include the development of vector clocks, checkpointing and message logging protocols, correct protocols for detecting stable properties such as distributed deadlocks and termination, mutual exclusion algorithms, garbage collection protocols, cache coherency and file coherency protocols in distributed replicated file systems, distributed debugging protocols, protocols for total message order and causal message order in group communication systems, global virtual time algorithms used particularly in parallel and distributed simulations of discrete event systems, and collaborative sessions and editing protocols in wide area systems and on the grid."

Congratulations as well to Bernhard Haeupler, who was awarded the Principles of Distributed Computing Doctoral Dissertation Award! Bernhard's dissertation was entitled "Probabilistic Methods for Distributed Information Dissemination", supervised by Jonathan Kelner, Muriel Médard, and David Karger at MIT. The award is jointly sponsored by PODC and DISC was given at DISC. The citation (`http://www.podc.org/dissertation/2014-dissertation-award/`) is:

> "Bernhard Haeupler's thesis provides a sweeping multidisciplinary study of information dissemination in a network, making fundamental contributions to distributed computing and its connections to theoretical computer science and information theory. The thesis addresses an impressive list of topics to which Dr. Bernhard Haeupler contributed significantly. These topics include the design and analysis of gossip protocols overcoming the dependency to connectivity parameters such as conductance, the introduction of a completely new technique for analyzing the performance of network coding gossip algorithms, and new randomized protocols for multi-hop radio networks. These are just a few samples of the very many important contributions of Dr. Bernhard Haeupler's thesis, and the work in this dissertation is distinguished by an impressive combination of creativity, breadth, and technical skill."

The first invited article of the column is a review of PODC 2014 by Oksana Denysyuk. The winner of the Best Student Paper award was Mohsen Ghaffari for his paper "Distributed Connectivity Decomposition," coauthored with Keren Censor-Hillel and Fabian Kuhn. The Best Paper Award was given for the paper "Signature-Free Asynchronous Byzantine Consensus with $t < n/3$ and $O(n^2)$ Messages," by Achour Mostéfaoui, Hamouma Moumen and Michel Raynal. Congratulations to Mohsen, Achour, Hamouma, and Michel! I cannot resist making my own contribution to the PODC review with the photo above.

The second invited article is a review of DISC 2014 by Merav Parter and Edward Talmage. Merav won the Best Student Paper award for her single-author paper "Vertex Fault Tolerant Additive Spanners". Ho-Lin Chen, Rachel Cummings, David Doty and David Soloveichik received the Best Paper Award for their paper "Speed Faults in Computation by Chemical Reaction Networks." Congratulations to Merav, Ho-Lin, Rachel, David and David!

Figure 1: PODC 2014 speakers: Leslie Lamport, Michael Luby, and Silvio Micali.

As reported in the previous article, part of the fun of DISC was all the ancillary activities, which included two workshops and a tutorial session. A detailed review of the workshop on Biological Distributed Algorithms is provided by Mira Radeva in the last invited article of this column.

Many thanks to Oskana, Merav, Edward, and Mira for their contributions!

Call for contributions: I welcome suggestions for material to include in this column, including news, reviews, open problems, tutorials and surveys, either exposing the community to new and interesting topics, or providing new insight on well-studied topics by organizing them in new ways.

Review of PODC 2014

Oksana Denysyuk
INESC-ID, Universidade de Lisboa
Lisbon, Portugal
oksana@gsd.inesc-id.pt

The 33rd 2014 ACM Symposium on Principles of Distributed Computing (PODC' 14) was held on July 12–15, 2014, in Paris, France. The main conference and its satellite workshops took place in the Pierre-and-Marie-Curie University, in central Paris. The convenient location allowed the participants to fully enjoy Paris in their free time—Seine, Notre Dame, Louvre, and Quartier Latin were just minutes away from the conference venue.

We begin the review with some statistics and then cover each day of the event briefly mentioning some of the many interesting and inspiring talks given at the conference and the workshops.

This year, the conference received 141 regular submissions and 23 brief announcements, of which 39 papers and 11 brief announcements were accepted. The resulting technical program covered a wide variety of topics related to distributed computing, including problems in message passing and shared memory systems, radio networks, distributed graph algorithms, fault tolerance, security, and game theory. In total, 208 attendees registered for the event this year.

The Day Before

The conference was preceded by five interesting workshops with the following titles: Adaptive Resource Management and Scheduling for Cloud Computing (ARMS-CC), Realistic models for Algorithms in Wireless Networks (WRAWN), Distributed Software-Defined Networks (DSDN), Theoretical Aspects of Dynamic Distributed Systems (TADDS), and Workshop on the Theory of Transactional Memory (WTTM). The workshop programs revealed invited talks of high quality and regular presentations on a wide variety of topics.

I attended DSDN workshop, which focused on theoretical issues in software defined networking (SDN). The research on software defined networking originated in the systems and networking communities, and now this topic is bringing new theoretical challenges for the PODC/DISC community to address.

The workshops were followed by a celebration of Maurice Herlihy's work on the occasion of his sixtieth birthday. During the celebration, the invited speakers covered Maurice's contributions on a

Figure 1: PODC 2014 Reception Party

variety of subjects. Sergio Rajsbaum and Michael Scott discussed Maurice's work on topology and transactional memory, respectively. Tim Harris, Mark Moir, and Vassos Hadzilacos talked about concurrent data structures and the wait-free hierarchy. And Nir Shavit gave a personal perspective on Maurice as a scientist and friend.

The day ended with the PODC reception, which took place on the 24th floor of the University tower, with a breathtaking panoramic view of central Paris, lots of Champagne, and a dancing lesson!

First Day

The first day of the conference began with the opening remarks by the PC Chair Shlomi Dolev. The remarks were followed by the invited talk by Silvio Micali entitled *Rational and Resilient Protocols*. Silvio discussed the opportunity for cryptography and distributed computing to join forces to study more general and accurate models of interaction. In Silvio's view, to design more realistic and resilient protocols, one should simultaneously take into account utility, collusion, and privacy. While it is common to tackle collusion and privacy issues, Silvio believes that the PODC/DISC community should also incorporate *utility* into the frameworks used to design and analyze distributed algorithms.

The regular program began with an energetic talk by Michel Raynal on *Signature-Free Asynchronous Byzantine Consensus*, co-authored by Achour Mostéfaoui and Hamouma Moumen. Michel presented a consensus algorithm that relies on a common coin as defined by Rabin, and a new simple all-to-all broadcast abstraction suited to binary values. The elegance and simplicity of the solution were evident, and the paper was rewarded with this year's Best Paper Award.

Rachid Guerraui gave a talk on *A Paradox of Eventual Linearizability in Shared Memory*, co-authored by Eric Rupert. The paper compares the computational power of linearizable objects with that of eventually linearizable ones. Interestingly, the paper shows that any implementation of an eventually linearizable complex object like a fetch&increment counter (from linearizable base objects), can itself be viewed as a linearizable implementation of the same fetch&increment counter (using the exact same set of base objects). Rachid's talk generated a lively discussion afterwards.

Figure 2: Leslie Lamport's Turing Lecture

Calvin Newport presented two papers on the recent advances with the abstract MAC layer model; the goal of this model is to capture main guarantees provided by most wireless MAC layers.

The first day ended with the business meeting and Dijkstra Prize Ceremony. The 2014 Dijkstra Prize was given to the paper *Distributed Snapshots: Determining Global States of Distributed Systems*, authored by Kanianthra Mani Chandy and Leslie Lamport.

Second Day

The second day started with the keynote talk on *Coding Theory for Scalable Media Delivery* by Michael Luby. The author gave a brief overview of the history of design, implementation and usage of erasure codes. Michael also described the RaptorQ code as an example of a result of years of collaborative coding theory research; RaptorQ has sophisticated theoretical foundations and supports a wide range of use cases.

After the keynote talk, Fabian Kuhn presented *Distributed Connectivity Decomposition*, co-authored by Keren Censor-Hillel and Mohsen Ghaffari; the paper was this year's winner of the Best Student Paper Award.

Dahlia Malkhi presented *Optimal Gossip with Direct Addressing*, co-authored by Bernhard Haeupler. The paper presents a simple gossip algorithm which spreads a message in only $O(\log\log n)$ rounds with high probability in the gossip model with direct addressing; the authors also show their algorithm to be asymptotically optimal in this model.

Eli Gafni presented *Generalized Asynchronous Computability Theorem*, co-authored by Petr Kuznetsov and Ciprian Manolescu. The presentation generated many questions and a lively discussion.

The highlight event of this year's PODC edition was Leslie Lamport's Turing Award lecture entitled *An Incomplete History of Concurrency, Chapter 1. 1965—1977*. The lecture focused on the problem of mutual exclusion in concurrent programming. Leslie discussed his Bakery algorithm, which has become textbook material in undergraduate computer science courses, and—as we discovered during the presentation—one of Leslie's favorite personal contributions. The lecture

 

Figure 3: Left: At DSDN workshop. Right: At the banquet.

was followed by a lively Q&A session, in which Leslie was asked to give his personal perspective on the history and evolution of the research in distributed computing.

In a good French tradition, the Turing Award lecture was followed by a Champagne hour, after which the attendees headed to the banquet, which took place in an exquisite 17th century palace called la Maison des Polytechniciens.

Third Day

The third day started with the keynote talk on *Rigorous System Design* by Joseph Sifakis. In his talk, Joseph advocated the use of rigorous system design as a coherent model-based process that starts from the requirements and leads to the implementations. Joseph discussed the state of the art in system design, its current limitations, and possible avenues for overcoming them.

Following the keynote talk, the morning session included several presentations addressing cryptographic advances related to distributed computing.

Later that day Magnús M. Halldórsson gave an interesting talk titled *Beyond Geometry: Towards Fully Realistic Wireless Models*, co-authored by Marijke H. L. Bodlaender. The paper proposes an extension to the traditional SINR model, which assumes smooth geometric decay of signals; the extended model allows arbitrary decay settings.

In the last session, Zahra Aghazadeh presented *Making Objects Writable*, co-authored with Wojciech Golab and Philipp Woelfel. The paper proposes a technique for augmenting shared objects in the standard shared memory model with a linearizable *write* operation, using bounded space and optimal worst-case step complexity.

The organizers reserved a special treat for the very last break—the most persistent attendees were rewarded with a scoop of a delicious ice-cream!

Future

Next year PODC will continue in Europe. The 34th ACM Symposium on Principles of Distributed Computing will take place in July 2015, in San Sebastián, Spain.

Acknowledgements

The highest quality of the technical program was ensured by the hard work of the PC Chair Shlomi Dolev and all members of Program, Conference, and Steering Committees. The local organization team, led by Sylvie Delaët, Maria Gradinariu Potop-Butucaru, and Sébastien Tixeuil, did an amazing job in running the conference smoothly and enjoyably.

I am grateful to Sébastien Tixeuil and Sanjai Narain for kindly providing pictures for this document.

DISC 2014 Review

Merav Parter
The Weizmann Institute
Rehovot, Israel
merav.parter@weizmann.ac.il

Edward Talmage
Texas A&M University
College Station, TX, USA
etalmage@tamu.edu

The 28th International Symposium on Distributed Computing, DISC 2014, was held in Austin, Texas from October 11-15, 2014. The event was hosted and organized by Mohamed Gouda of the University of Texas at Austin.

The event included two days of workshops and tutorials, followed by three days of the main conference, from October 13th to the 15th. This review attempts to give a quick glimpse of the event. We apologize in advance for talks that are not included due to space limitations.

The first workshop, BDA (Biological Distributed Algorithms), was on Saturday and Sunday, 11-12 October 2014. The goal of the workshop was to bring together the conventional DISC audience and open minded biologists to lay the basis for interdisciplinary cooperation. The talks were given by representatives from both communities. For example, Nancy Lynch (CSAIL, MIT) gave an inspired talk on the general theme of distributed algorithms and biological systems. Deborah Gordon, biologist at Stanford University, told us about the behavior and ecology of ant colonies. Ant colonies are a good model for studying real distributed systems as they operate without central control, using networks of local interactions to regulate their behavior. In a seminal work, Amos Korman and Ofer Feinerman presented the first distributed computing tools to provide a new perspective on the behavior of cooperative biological ensembles. This framework has become quite popular since then. The most recent work in this area appears in this conference [5]. Besides the invited talks, the workshop also included a brainstorming session aiming at suggesting potential projects in which biology can guide the design of distributed algorithms. Overall, the workshop was a great success in which both communities felt they learned from each other.

The second workshop ADGA (Advances in Distributed Graph Algorithms) lasted one day, October 12. The program consisted of several invited talks. Keren Censor-Hillel's talk on distributed algorithms as combinatorial structures was a favorite. The main take-home message of the talk was that both distributed algorithms and lower bound proofs can be used to study combinatorial graph structures.

Also held on October 12 were three tutorials. During the morning, Emin Gün Sirer and Ittay Eyal from Cornell gave a tutorial entitled "Bitcoin: Concepts, Practice, and Research Directions."

The afternoon's tutorials were "Agents and Reagents: Distributed Systems in a Test Tube", given by David Doty (Caltech) and David Soloveichik (UCSF), and "Link Reversal Algorithms", presented by Jennifer Welch (Texas A&M).

The next day was the first day of the main conference. The session started with a keynote talk, given by Kanianthra Mani Chandy (Caltech). The talk gave a comprehensive review on concurrent computing scanning the main transformations of this area in the last 40 years. Chandy pointed out, for example, that nowadays young researchers have better programming skills compared to the older generation, studying fast from examples (e.g., through web searches) instead of reading the long manuals and understanding deeply the (mostly irrelevant) theory from books. This talk was inspiring, it pinpointed several "philosophical" observations that are extremely valuable coming from someone with such an experience. Following this talk, Pierre Fraigniaud (CNRS) discussed the tradeoff of concurrency and asynchrony. He proposed a mechanism similar to state machine replication, called RC-simulation where RC stands for *Reduce Concurrency*, that can always make progress, even if the system is never synchronous. He discussed several applications of the RC-simulation, such as the renaming and k-set agreement problems.

The next session was on chemical and biological networks. This session was opened by the best paper presentation on chemical reaction networks (CRNs) [1]. The talk considered speed faults in CRN—the situation where the system might (with low probability) reach a state from which the correct answer may only be computed by executing a slow reaction. Interestingly, the problems guaranteed to *avoid* speed faults are precisely the set of detection problems, i.e., Boolean combinations of questions of the form "is a certain species present or not?". In contrast, speed-fault-free CRNs cannot count and so, for instance, no speed-fault-free CRN can decide whether there are at least two molecules of a certain species.

The other two sessions of that day were devoted to agreement problems, robot coordination and scheduling. One of the talks that we liked most in these sessions was that of Yoram Moses (Technion) which discussed unbeatable consensus [3]. Yoram made the quite funny observation that many works in this area present an optimal algorithm compared to the previous algorithm that was "optimal" as well. This results from the fact that the very first consensus protocols for the synchronous model were designed to match the worst-case lower bound, and hence considered to be optimal. Later papers attempt to improve this optimal protocol by providing early stopping. To avoid this undesired situation where an "optimal" protocol improves another "optimal" protocol, Yoram presented the notion of *unbeatability*. Generally speaking, a protocol is unbeatable if it can't be strictly dominated by another protocol (i.e., there exists no protocol that decides strictly faster). The take-home message of the talk was that unbeatability is a much more suitable notion of optimality for distributed protocols than worst-case performance.

The day's final event was the business meeting. It began with the presentation of the best dissertation award to Bernhard Haeupler from CMU for his thesis "Probabilistic Methods for Distributed Information Dissemination". Bernhard was supervised by Professors Jonathan Kelner, Muriel Médard, and David Karger at MIT. One of his most citeable papers [6] provides an extremely neat and simple analysis of gossip protocols that are based on random network coding. Congratulations, Bernhard!

Following that, the best paper award was presented to Ho-Lin Chen, Rachel Cummings, David Doty and David Soloveichik for their paper "Speed Faults in Computation by Chemical Reaction Networks" [1]. The best student paper award went to Merav for the paper "Vertex Fault Tolerant Additive Spanners" [2].

The meeting also included short announcements made by the PC members. Among these, Keren Censor-Hillel (Technion) presented the new web-site for DISC (http://www.disc-conference.org/wp/), constructed in cooperation with Chen Avin (BGU). This site contains the information about WDAGs and DISCs since 1985! Finally, the meeting turned to consider future DISC events. The next two DISC events will be held in Tokyo and Bucharest (2015 and 2016, respectively). Representatives from these locations presented highlights of each. Two optional locations were presented for DISC 2017: Oslo and New Orleans. This was followed by a quick vote which slightly favored Oslo.

Figure 1: Bernhard Haeupler receiving the dissertation award from Pierre Fraignaud for his thesis "Probabilistic Methods for Distributed Information Dissemination".

Tuesday opened with the *Graph Distances and Routing* session. The first talk was for the best student paper, by Merav, who showed the construction of fault-tolerant additive spanners that are resilient against vertex faults. Following her, Roei Tov (Bar-Ilan University) showed the construction of nearly linear-space routing schemes. Then Mohsen Ghaffari (MIT) described the first distributed algorithm for tree-embedding; Mohsen and Christoph Lenzen (Max-Planck) provided a distributed implementation for the well-known FRT algorithm of Fakcharoenphol, Rao, and Talwar. An interesting brief announcement was made afterwards by Noy Rotbart (University of Copenhagen) who discussed dynamic and multi-functional labeling schemes. What surprised us in this talk was the fact that providing tight bounds for the size of the labels seems to be *easier* in the dynamic setting. Noy also discussed the notion of multi-functional labels that support multiple functions (i.e., connectivity+adjacency).

After a break, the session on radio networks began. The talk that we liked most in this session, was that of Calvin Newport (Georgetown University) which presented a general framework for providing lower bounds for radio networks [4]. Calvin described an impressive list of lower bounds that are based on a reduction from a probabilistic hitting game. This framework simplifies many existing results and also provide some new bounds. For example, with this framework it is no longer required to assume that the protocols are uniform (which was a common assumption when studying broadcast protocols). The last session of this day was devoted to shared memory.

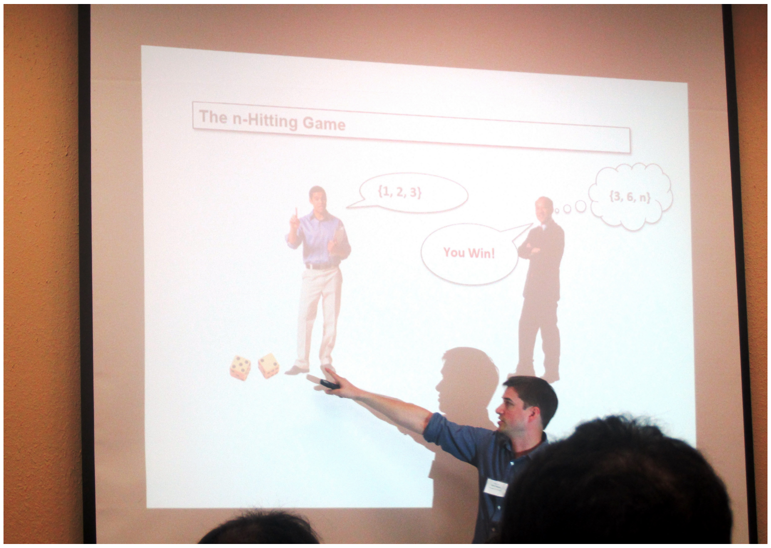

Figure 2: Calvin Newport presenting a new framework for lower bounds in radio networks.

Kfir Lev-Ari (Technion) opened the afternoon with a discussion of reads-write concurrency in data structures. Following him, Claire Capdevielle (University of Bordeaux, LaBRI) presented on determinisic abortable objects. She gave a solo-fast universal construction to turn any sequential object into a deterministic abortable object and gave a lower bound on the necessary number of registers.

From the University of Calgary, Philipp Woelfel next discussed the space complexity of renaming. He pointed out that while the step complexity of renaming algorithms is a popular topic of research, no work has been previously done on space complexity. He therefore presented several bounds, upper and lower, on the space complexity of several variants of the renaming problem. Rounding out this session, Sebastiano Peluso and Wei-Lun Hung gave brief annnouncements on impossibility results in transactional memory and non-blocking monitors, respectively.

The last session of Tuesday concerned dynamic and social networks. Giving his third talk of the conference, Calvin Newport discussed lower bounds in unreliable radio networks. He talked about the necessity of knowledge of geography and link reliability. Next, Oksana Denysyuk (University of Lisbon) presented on methods to evaluate random walks in evolving graphs. Since the choice of next steps depends on the current graph, as well as the location, the problem is much more difficult than a simple random walk. To work around this, she proposed a method that relies on a family of specific graphs that repeats frequently as the whole graph evolves. Considering these reduces the problem to the static case.

Ali Vakilian gave a brief announcement for Adam Sealfon and Aikaterini Sotiraki (MIT) on agreement in partitioned dynamic networks, discussing what knowledge is necessary to solve the problem. Christoph Lenzen (MPI) presented a toolkit for building balls-into-bins algorithms, and finally, Pierre Fraigniaud (CNRS) presented a space-optimal self-stabilizing spanning tree construction.

The third and final day of the conference opened with a keynote talk by Phil Bernstein from Microsoft Research. Phil spoke on Project Orleans, a cloud computing programming framework.

Orleans provides a variety of useful features and optimizations which lead to its widespread use in Microsoft products. Following him, Wojciech Golab (University of Waterloo) presented research on relativistic distributed systems. He discussed the challenges of achieving coordination between nodes which are dealing with relativistic speeds and the ensuing time distortion. He presented several possible consistency conditions, including one which restores locality of objects, one of the first problems that arises when time is no longer global.

The next session was devoted to transactional memory and concurrent data structures. Sandeep Hans (Technion) opened the session by talking about the safety of live transactions. He showed a necessary and sufficent condition for safety, if rollbacks are allowed. Next, Mohsen Lesani (UCLA) discussed approaches for proving opacity. He presented a new condition, *markability*, which is necessary and sufficient for opacity, and breaks down into three invariants, allowing a simpler, modular proof.

Transitioning to data structures, Irina Calciu (Brown University) described a new implementation of a priority queue, using a variety of techniques to avoid several performance and scalability bottlenecks common to priority queues. Edward Talmage (Texas A&M University) concluded the session with a talk on time bounds for implementations of relaxed data structures in message passing systems. He showed that by sacrificing the strict behavior of a data structure, the time cost can be lowered below the previous lower bound for unrelaxed data structures.

After lunch, Hsin-Hao Su opened the distributed graph algorithms session with his talk on minimum-cut algorithms. He gave both approximate and exact algorithms which were near-optimal, the approximate algorithm being within a polylog factor of a known lower bound. Next Christian Konrad (Reykjavik University) gave algorithms for covering interval graphs, including upper and lower time bounds. The last full talk of this session was by Danupon Nanongkai (University of Vienna), presenting the second paper on which he was an author, having co-authored the first paper in this session. He talked about minimal vertex covers and maximal independent sets and their use in hypergraphs to break symmetry.

To complete the session, there were two brief announcements, both given by Stephan Holzer of MIT. In the first, he talked about bounds on k-selection and sorting and in the second, he talked about an approximate distributed algorithm for determining the diameter of a graph.

For the final session of the conference, numbers had thinned as attendees' travel plans took some of them away early, but a strong contingent stayed for every talk. Ali Vakilian (MIT) discussed the complexity of the set cover problem, specifically considering streaming and communication complexity, considering approximate algorithms. On behalf of authors Yi Li, Xiaoming Sun, Chengu Wang and David Woodruff, Hsin-Hao Su presented work on communication complexity of linear algebra problems, reducing the complexity of multi-player problems to an expression in terms of the complexity of two-player problems. Vivek Sardeshmukh (University of Iowa) gave the last full talk of the conference, discussing various problems which can be solved very efficiently on a congested clique.

To wrap things up, Mahdi Zamani and Mahnush Movahedi (University of New Mexico) gave back-to-back brief announcments of their work in securing broadcast while maintaining anonymity and preserving privacy while using location-based services.

Banquet. For the conference banquet, Mohamed Gouda organized a river cruise. Buses transported conference attendees to the Colorado river on the west side of Austin. Once there, everyone boarded two boats and relaxed as the sun set and dinner was served. The cruise lasted two hours, and provided great views of the Texas hill country.

Figure 3: Waiting to start the cruise.

This was our third time in DISC. We really enjoyed it, and hope to see everyone again next year in Tokyo!

References

[1] H. Chen, R. Cummings, D. Doty and D. Soloveichik. Speed Faults in Computation by Chemical Reaction Networks. In *DISC*, 16–30, 2014.

[2] M. Parter. Vertex Fault Tolerant Additive Spanners. In *DISC*, 167–181, 2014.

[3] A. Castaneda, Y. Gonczarowski and Y. Moses. Unbeatable Consensus. In *DISC*, 91–106, 2014.

[4] C. Newport. Radio Network Lower Bounds Made Easy. In *DISC*, 258–272, 2014.

[5] A. Cornejo, A. Dornhaus, N. Lynch and R. Nagpal. Task Allocation in Ant Colonies. In *DISC*, 46–60, 2014.

[6] B. Haeupler. Analyzing network coding gossip made easy. In *STOC*, 293–302, 2011.

Review of BDA Workshop 2014

Mira Radeva
Massachusetts Institute of Technology
Cambridge, MA, USA
radeva@csail.mit.edu

The second workshop on Biological Distributed Algorithms (BDA) was a very insightful and productive gathering of theoretical computer scientists and biologists with the common goal of borrowing some extra knowledge, techniques and ideas from each others' areas and starting some collaborations. The topics varied widely, ranging from slime mold constructing shortest paths, to ant colonies making optimal decisions without centralized knowledge, to numerous algorithms and lower bounds modeling the capabilities and strategies of different organisms. Below is a more in-depth description of some of these topics. This review ends with a summary of the issues that started some heated discussions between biologists and computer scientists throughout the workshop.

Some of the Main Topics

Formal Models: One of the key points many speakers made is that it is important to design computational and biological models with two main goals in mind: (1) use inspiration and ideas from biology to design better distributed algorithms, and (2) use tools and techniques from distributed algorithms and computer science, in general, to better understand and predict biological systems. With these two strategies in mind, different speakers had different ideas for modeling such systems.

Nancy Lynch gave an overview of the basic models and ideas from distributed computing research focusing on the key technique of designing models that separate the platforms from the problems to be solved from the algorithms that solve the problems. Nancy also gave examples of typical distributed computing problems (consensus, synchronization, counting, resource allocation) and some simple algorithms and lower bounds (impossibility results). An example of a formal distributed computing model was later given by Stephan Holzer, who presented the Stone Age Model. The model is designed to be as weak as possible, while still allowing to solve many problems, with the goal of roughly matching the computational capabilities of a cell. Stephan described numerous problems that can and cannot be solved in this model, while emphasizing that assuming a leader exists in such a model makes many of the unsolvable problems become solvable.

Anna Dornhaus and Radhika Nagpal also touched upon the importance of formal models in bridging the gap between social insect biology and distributed computing. Anna gave specific examples of how designing mathematical models and simulations can help understand the foraging strategies of ants; she also emphasized the importance of understanding why the models are the way they are by giving examples of bumble bees performing waggle dances to inform other bees about the direction of foraging. Radhika also emphasized the two directions of the interaction between biology and distributed algorithms by showing numerous demos about robots in her lab that try to achieve goals (building large structures, forming patters) similar to insect colonies, and using the resulting empirical insights to learn something new about insects.

Figure 1: Anna Dornhaus, BDA speaker. Photo courtesy Yuval Emek.

Consensus and Symmetry Breaking: Consensus is one of the most widely-studied problems in distributed algorithms, and is also a very basic problem that social insect colonies solve. A number of speakers talked about the house-hunting process of both ants and bees, in which the colony of insects needs to move from its current nest to a new one maximizing different utility functions.

Stephen Pratt described in detail the house-hunting process of the *Temnothorax* ants and focused on two main results evident from his experiments and simulations. First, the algorithm the ants use can be tuned based on the urgency of the move (the current nest is destroyed vs. there is a better nest naturally occurring) to maximize either the speed or the accuracy (picking a high quality nest) of the moving process. Second, his results also point to evidence that a colony has a greater cognitive capacity than a single ant when it comes to making difficult decisions (many similar candidate nests); however, if the task of choosing a new nest is easy, then a single ant performs more reliably in picking the obviously-superior nest.

A different approach to the same problem was presented by Mira Radeva who described an abstract distributed computing model that captures the basic capabilities and restrictions of the *Temnothorax*. Mira showed that using simple results and techniques from distributed computing theory it can be shown that the time required for the house-hunting and moving process of n ants is at least of the order of $\log n$ concurrent steps by the ants. Also, a very simple algorithm can be shown to match this bound.

James Marshall also talked about the house-hunting process but he focused on the honey bee. He showed how to apply a statistically-optimal test to determine if the process of bees choosing a new nest is optimal in terms of the speed vs. accuracy trade-off. An optimal solution corresponds to a specific threshold for making a decision (choosing the correct nest) that can be estimated by simulating stochastic differential equations. James' results point to evidence that the use of inhibition signals by bees to stop other bees from recruiting is crucial in the bees' ability to make an optimal decision.

Foraging and Navigation Numerous speakers gave examples of insect colonies and other organisms navigating through obstacles in search of food. Saket Navlakha explained how *E. coli* bacteria use both individual information and information from their neighbors (using bacterial chemotaxis) while foraging for food. Shashank Singh also discussed the behavior of bacteria navigating through obstacles while foraging, focusing on the three main strategies of movement: (1) repulsion from the closest neighbors to avoid collision, (2) orientation towards bacteria at medium distance to accelerate picking the correct direction and to avoid collisions, (3) attraction towards bacteria far away to keep the swarm together. In Saket's example, a critical parameter in this process is the *plasticity* of the group which defines how much bacteria listen to their neighbors. Shashank discussed modeling this behavior in simulations and trying to match the actual bacteria behavior by experimenting with different communication capabilities.

Deborah Gordon approached the foraging problem from the point of view of harvester ants. When returning foragers come back to the nest, they interact with potential foragers by a simple positive feedback process: the more food comes back to the nest, the more new foragers go out searching. The individual decision rule that determines whether a forager goes out searching for food can be thought of as an activation threshold (of interaction rates with other ants) after which the probability of an ant going out increases. Deborah is also interested in studying the evolutionary aspect of the foraging process by censusing the same colonies for many years (since 1985).

The topic of ant foraging was also discussed by computer scientists. Tobias Langner and Roman Kecher presented formal models and algorithms that prove some bounds on the optimal time for foraging. Tobias considered different ways to model ants and for each possibility, he showed what is the minimum number of ants needed to solve the foraging problem. For example, he showed that if ants are modeled as finite state machines, four ants are enough to find the target (three ants, if they operate synchronously), and no algorithm can solve the problem using just two ants. Roman considered ants that have the capability to deposit pheromones and showed that if ants are modeled as finite state machines, then at least D (the distance of the target from the nest) pheromones are needed to find the food, while if ants are modeled as Turing machines, then at least k (the number of ants) pheromones are needed to solve the problem optimally.

A notable example, mentioned by a few speakers, of organisms' capability to navigate through unknown environments is the process of slime mold building a shortest-path network between food sources. Saket Navlakha talked about an experiment in which the slime mold was given various food sources, similar in spatial dispersal to the map of Tokyo, and the resulting network built by the slime mold was extremely efficient and resembled closely the actual railway map of Tokyo. It has been conjectured that the slime mold uses strategies similar to network flow methods to solve the problem.

Finally, Ofer Feinerman presented his work on a different aspect of navigation in ant colonies: cooperative load transport in the presence of obstacles. In this transport process, Ofer is interested in how much ants conform to the colony's idea of the direction in which to go, and how much they trust their own judgment. The key results Ofer mentioned are: (1) as the number of ants increases, the speed of carrying the object increases and it is independent of the distribution of ants around the load, and (2) an informed ant makes a positive difference in bringing the object in the right direction; each such leader ant helps carry the object in the right direction. This enables the actual ant transport system to behave somewhere in between a random walk (corresponding to very independent ants) and ballistic motion (corresponding to very conformist ants).

Task Allocation The problem of task allocation was brought up by a few speakers as an essential problem in most ant colonies. Alex Cornejo presented a distributed-computing style model and algorithm to tackle the problem and provide one possible explanation to the question of why certain ants are idle sometimes. Alex abstracted the problem as a set of ants A trying to pick one task each (or no task) from set of tasks T, while minimizing both underproduction and overproduction of energy for each task. The only information each ant has about the current tasks is just a sense of whether there is a demand or a deficit of energy for that task. Alex presented a very simple algorithm, together with a correctness proof and analysis, which essentially does, for each ant, a binary search over all tasks to be allocated while offloading the memory requirement for such a search from individuals to the colony.

On the more biological side of the task allocation problem, Laurent Keller explained how ants pick different roles throughout their lifetimes. In an experiment Laurent performed in his lab, they noticed that ants split into groups based on their interaction with each other and these groups roughly correspond to different tasks to be performed at the nest: nursing, foraging, nest cleaning. The experiments also show that the typical sequence of transitions for each ant throughout its lifetime is from being a nurse to being a cleaner to being a forager.

Deborah Gordon also touched upon the subject of task allocation in ants. She considered the dynamical version of the problem where colonies adjust the effort in various tasks in response to changing conditions in the environment. Deborah conjectured that task allocation and colony size are related to the interaction rates between ants: task switching seems to be more consistent in larger colonies than in smaller colonies even though ants are of the same age in both colonies. Deborah's experiments focus on manipulating the interaction rates between ants, which are used as a cue to local density.

Pattern Formation and Structure Building Radhika Nagpal and Andrea Richa talked about their research in robotics and emphasized some connections between robots and biological organisms. Radhika Nagpal showed some very exciting videos of robots in her lab building structures together and forming various patterns. Radhika introduced the TERMES robots that build a structure without the need to elect a leader, which can be expensive and slow in her setting. She also demonstrated how the Kilobots (1000 tiny robots) form different patterns in her lab, showing that robots can also operate at a scale similar to real social insect colonies.

Andrea Richa focused on the concept of programmable matter and the models and algorithms considered in such applications. Programmable matter can be thought of as multiple particles, moving and bonding with each other, trying to form a global spatial pattern. Applications of programmable matter include self-organizing nano-sensors, robot swarms, modular robots, etc. Andrea gave the specific example of such particles trying to coat a surface using a hexagonal tiling by forming spanning trees rooted at particles touching the surface. Using this basic strategy, particles can also form multiple layers on a surface and also form various shapes starting from a seed particle.

Miscellaneous A few talks did not necessarily fit into the above categories but still had interesting connections between social insect colonies and distributed algorithms. Amos Korman described a problem where each agent in a distributed system has an opinion of the value of some environment parameter θ, such that the initial opinion of each agent is drawn from some distribution with mean θ. The goal is for the agents to use some communication between each other in order to improve their estimates such that each opinion is an unbiased estimator of θ and minimizes the variance around the random variable describing the opinions of the agents. Assuming the meeting pattern between the agents is adversarial, Amos described a lower bound which expresses the information of two agents after they communicate as Fisher information and bounds from below the variance between the opinions of any two agents. Amos also showed a simple algorithm to match the lower bound.

Ted Pavlic talked about the colony-level macronutrient regulation that occurs when individual ants need to decide what nutrient is needed for the well-being of the colony. Given two food sources, one rich in carbohydrates, and one rich in protein, ants always cluster at some middle point of concentration between the two. The same experiment performed with adult ants and with larvae shows that the middle point is shifted towards protein in the case of larvae. Theoretically, choosing the correct middle point is difficult to solve distributively without sending a lot of messages. Ted approached this as an optimization problem where solutions (the correct "middle-point") are guaranteed to exist and be unique. Figuring out how to do this without sending many messages may have many applications in engineering. Also, studying the problem in such a way helps figure out whether ants are reaching their micronutrient goals properly, without getting excess of any of them.

Discussions

Last but not least, it is worth mentioning that throughout the workshop there were a few conceptual issues of discussion and potential disagreement between biologists and computer scientists.

Separation of platforms and algorithms: The very first issue that arose was the inclination of computer scientists to separate the platform (the environment and the agents' capabilities and restrictions) from the problem statement and from the solutions to the problem. Biologists, on the other hand, tend to consider the environment, together with the organisms and their behavior, and then try to study and model this complex system. While it may be more convenient to analyze solutions with a clearly-separated platform and algorithms, biologists made the point that, as observers of the natural behavior of organisms (in real life or in an experimental setup), it is not always easy to know precisely how to separate these layers of abstraction.

"Realistic" algorithms: Biologists pointed out that sometimes what computer scientists call "realistic" models and algorithms are actually quite far from the actual organism behavior observed in nature. While biologists do not necessarily and always focus on models matching reality, they made a point about using the term "realistically" with more care.

Leader election: Biologists found one common aspect of many computer science talks to be a little surprising and unnatural. Why do we always try to elect a leader? While leader election is one of the basic and widely-studied problems in distributed algorithms, the concept of having a leader ant (disregarding the queen) is not common in insect colonies at all. One explanation computer scientists mentioned is that electing a leader makes it easier to solve many problems because now the problem can be treated in a more centralized way.