

Distributed Computing Column 60

Annual Review 2015

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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 Michael Ben-Or and Michael O. Rabin who received the 2015 Dijkstra Prize for starting the field of fault-tolerant randomized distributed computing! Michael Ben-Or's paper was "Another Advantage of Free Choice: Completely Asynchronous Agreement Protocols" and Michael Rabin's paper was "Randomized Byzantine Generals". The prize is jointly sponsored by ACM and EATCS, and is given alternately at PODC¹ and DISC²; this year it was given at DISC. The full citation can be found at <http://www.podc.org/dijkstra/2015-dijkstra-prize/>; highlights are:

"Ben-Or and Rabin were the first to use randomness to solve to a problem, consensus in an asynchronous distributed system subject to failures, which had provably no deterministic solution. In other words, they were addressing a computability question and not a complexity one, and the answer was far from obvious... Ben-Or and Rabins algorithms opened the way to a large body of work on randomized distributed algorithms in asynchronous systems..."

Congratulations as well to Leonid Barenboim, who was awarded the Principles of Distributed Computing Doctoral Dissertation Award! Leonid's dissertation was entitled "Efficient Network Utilization in Locality-Sensitive Distributed Algorithms", supervised by Michael Elkin at Ben Gurion University. The award is jointly sponsored by PODC and DISC was given at DISC. The citation appears at <http://www.podc.org/dissertation/2015-dissertation-award/>. Leonid has provided some insights into his dissertation work in the first article of this column.

¹ACM Symposium on Principles of Distributed Computing

²EATCS Symposium on Distributed Computing

Spain was the place to be for distributed computing this past July. First, SIROCCO³ was held in Montserrat, and a few days later PODC started in Donostia-San Sebastián.

The next article is a review of SIROCCO 2015 by Marc Bury, who was one of the winners of the Best Student Paper Award for his paper “Randomized OBDD-Based Graph Algorithms.” The other winner was Katia Patkin for her paper “Under the Hood of the Bakery Algorithm: Mutual Exclusion as a Matter of Priority”, co-authored with Yoram Moses. Michel Raynal was the recipient of the SIROCCO Innovation Award in Distributed Computing for his work on the condition-based approach to fault-tolerant consensus. Congratulations to Marc, Katia, Yoram, and Michel!

The next article of the column is a review of PODC 2015 by Lewis Tseng. The winner of the Best Student Paper award was Mohsen Ghaffari for his single-author paper “Near-Optimal Scheduling for Distributed Algorithms”; this is the second year in a row that he has received this award. The Best Paper Award was given for the paper “Deterministic ($\Delta+1$) Coloring in Sublinear (in Δ) Time, in Static, Dynamic and Faulty Networks” by Leonid Barenboim; more about this work appears in the first article. Congratulations to Mohsen and Leonid!

The last article is a review of DISC 2015 by Hillel Avni and Rati Gelashvili. Rati won the Best Paper award for his single-author paper “On the Optimal Space Complexity of Consensus for Anonymous Processes”. Yuezhou Lv is the student author of “Local Information in Influence Networks”, which won the Best Student Paper award and was co-authored with Thomas Moscibroda. Congratulations to Rati, Yuezhou, and Thomas!

Many thanks to Leonid, Lewis, Marc, Hillel, and Rati 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.

³International Colloquium on Structural Information and Communication Complexity

Distributed Symmetry-Breaking from a Local Point of View

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I was very happy to receive the Best Dissertation and Best Paper awards during the PODC'15 conference that took place on July in Donostia - San-Sebastian, Spain. I wish to thank my advisor Prof. Michael Elkin without whom these achievements would not be possible. I am also grateful to the committees of the awards for selecting these works. In the current article I would like to briefly describe how these results were obtained, and provide a few highlights of the works.

Shortly after returning from a great post-doc period at the Simons institute at UC Berkeley, and just before starting another great post-doc period at the Weizmann institute, I was on my way to submitting (multiple copies of) my dissertation [1] to a library. I fell down the stairs, the multiple copies of the dissertation fell on me, and I broke my leg. This event led to several discoveries:

1. I needed an urgent surgery to fix my leg.
2. It may be better to avoid writing long and heavy dissertations.
3. Deterministic $(\Delta + 1)$ -coloring can be computed in sublinear (in Δ) time in static, dynamic, and faulty networks [3].

The last discovery is related to various results that appeared in my dissertation. It all started around nine years ago in Ben-Gurion University, when I first met my advisor Michael Elkin who introduced to me the problem of minimum forest-decompositions. This is the problem of partitioning the edge-set of a graph into the minimum number of acyclic edge subsets. (This number is also known as the *arboricity* of the graph). While a centralized algorithm had been well known, computing such a decomposition distributedly remained an open problem, even approximately. Together with Michael we obtained a distributed $(2 + \epsilon)$ -approximation that requires logarithmic time, and an $o(\log n)$ -approximation with sublogarithmic time. These results allowed us to obtain improved coloring and Maximal Independent Set algorithms for sparse graphs, which appeared in my MSc thesis and in PODC'08 [4].

Then I continued to PhD studies, again under the supervision of Michael. We began investigating $(\Delta + 1)$ -colorings in general graphs of maximum degree Δ . The best deterministic algorithm back then in terms of Δ was the algorithm of Kuhn and Wattenhofer [10] that requires

$O(\Delta \log \Delta + \log^* n)$ time. During our investigation we discovered that graph partitions with certain helpful properties turn out to be very useful for computing colorings. Specifically, suppose that for certain parameters t and k , one is able to partition the *vertex set* of a graph into t subsets of maximum degree $O(\Delta/k)$ each. Then each subset can be colored using $O(\Delta/k)$ unique colors, and the overall number of colors becomes $O(t \cdot \Delta/k)$. All the colorings are performed in parallel, and the running time depends on (Δ/k) , rather than on Δ . This allows speeding up coloring algorithms significantly, as long as the partition can be computed efficiently for appropriate values of t and k . The ultimate values are $t = k$, for $\omega(1) \leq k \leq O(\Delta)$, and obtaining such a partition remains a very challenging open problem to this day. On the other hand, for $t = k^2$ we were able to devise an algorithm that computes such a partition very quickly.

By setting $k = \log \Delta$, we obtained a partition into $\log^2 \Delta$ subsets of maximum degree $O(\Delta/\log \Delta)$ each. Then, by employing the $(\Delta + 1)$ -coloring algorithm of Kuhn and Wattenhofer that requires $O(\Delta \log \Delta + \log^* n)$ time on general graphs, we got $O(\Delta/\log \Delta)$ coloring in each subgraph within $O(\Delta + \log^* n)$ time. Since there are $\log^2 \Delta$ subgraphs, the overall number of colors becomes $O(\Delta \log \Delta)$. This number can be reduced to $(\Delta + 1)$ by using the technique of Kuhn and Wattenhofer within $O(\Delta \log \log \Delta)$ time. This resulted in a new algorithm with overall running time $O(\Delta \log \log \Delta + \log^* n)$, improving the best previously-known $O(\Delta \log \Delta + \log^* n)$ time. Denote this new algorithm of ours by \mathcal{A}_1 . If we partition the input graph into $(\log \log \Delta)^2$ subgraphs of maximum degree $O(\Delta/\log \log \Delta)$, we can employ the algorithm \mathcal{A}_1 in each subgraph, instead of the algorithm of Kuhn and Wattenhofer. This results in a $(\Delta + 1)$ -coloring of the original input graph within time $O(\Delta \log \log \log \Delta + \log^* n)$. Denote this new algorithm by \mathcal{A}_2 , and proceed in the same way. As a result we obtained infinitely many algorithms $\mathcal{A}_1, \mathcal{A}_2, \mathcal{A}_3, \dots$, each of which slightly improves the previous one. Specifically, \mathcal{A}_i has running time $O(\Delta \log^{(i+1)} \Delta + \log^* n)$ for any positive constant i . For superconstant i , the analysis is more delicate, but still we were able to obtain a $(\Delta + 1)$ -coloring algorithm that requires $O(\Delta + \log^* n)$ time. We joined forces with Fabian Kuhn who concurrently and independently obtained similar results, but using a different approach, and published a joint paper in SIAM Journal on Computing describing these two approaches [9].

Although we already had infinitely many algorithms, it was not enough for a PhD thesis. So Michael and I started to work on a more general kind of partitions. Instead of bounding the maximum degree of the graphs, we focused on partitions into subgraphs of bounded *arboricity*. Although the subgraphs may have unbounded degrees, such partitions still turned out to be very useful. Moreover, in this case the product of the number of subgraphs t and the arboricity in each subgraph k could be made linear. This is in contrast to our previous algorithms where the product was superlinear. This gave rise to several significant results [5], and in particular, a deterministic $O(\Delta^{1+\epsilon})$ -coloring algorithm in polylogarithmic time. This result settled a long-standing open question of Linal from 1987 [11] asking whether it is possible to color a graph with $o(\Delta^2)$ colors in deterministic polylogarithmic time. Next, we turned our attention to graphs of *bounded neighborhood independence*. This is a wide family that includes line graphs, claw-free graphs, and many other graphs. Interestingly, in this family bounding the arboricity results also in a bound on the maximum degree of subgraphs. This gave rise to even better algorithms, and in particular resulted in a deterministic algorithm with sublinear in Δ time for *edge coloring* [6]. At that time, the problem of sublinear (in Δ) algorithms for $(\Delta + 1)$ -vertex-coloring remained wide open.

Other questions that we investigated were: what can be computed using only very basic operations, and on the contrary, if an unbounded computational power is given to a processor, what can

be computed in a constant number of rounds? For the first question we showed that $(\Delta+1)$ -coloring can be computed in $O(\Delta + \log^* n)$ time using very basic operations [7]. This is in contrast to our original algorithm that required sophisticated structures and algebraic computations. The second question interested us because even with unbounded computational power of processors, only relatively simple tasks had solutions with a constant number of rounds. I was able to show that an $n^{1/2+\epsilon}$ -approximation of minimum coloring can be computed in a constant number of rounds [2]. In other words, there are NP-hard problems that can be computed locally! The last result may seem like a purely theoretical one, due to the unbounded local computational power. However, in a very recent work together with Michael and with Cyril Gavoille [8], we obtained constant-time distributed algorithms for a variety of non-trivial problems with reasonable local complexity, which makes it possible to employ them in practice. (These algorithms do not solve NP-hard problems of course, we still do not know how to do it efficiently in the centralized setting...)

The above-mentioned results formed my PhD thesis, which was also the cause of that fateful event on my way to the library. This event triggered me to look on some problems from a different angle. In particular, I began thinking of what happens if we are given a graph in which some parts are already colored, and we only need to find a proper solution for the uncolored parts. In a matter of fact, this is a more general problem than ordinary coloring, since in ordinary coloring the subset of a priori colored vertices is always an empty set. Although coloring partially-colored graphs is a harder problem, its generality provides more food for thought. I realized that the uncolored subsets can be partitioned into a few parts, each of which can be colored very quickly (within a single round per part, after a short preprocessing stage). Moreover, the coloring of each part can be made consistent with the already computed colors immediately. Since the number of parts is $o(\Delta)$, a sublinear (in Δ) deterministic $(\Delta + 1)$ -coloring algorithm is obtained. The ability to fix partial colorings and turn them into complete ones turned out to be very useful also in the dynamic and faulty settings. In these settings the network changes rapidly. But the ability to fix the parts that are no longer proper, or for which colors are missing, resulted in sublinear update-time algorithms in these settings as well. These results were published in my recent PODC'15 paper.

Finally, I would like to take this opportunity to encourage all of you to submit your papers to PODC'16, which will take place in Chicago on July 25 - 28. Also, I would like to encourage the fresh PhD graduates to apply for the Best Dissertation award. Just be careful when you go down the stairs.

References

- [1] L. Barenboim. Efficient network utilization in locality-sensitive distributed algorithms. *PhD Thesis*. 2013.
- [2] L. Barenboim. On the Locality of Some NP-complete Problems. In *Proc. of the 39th International Colloquium on Automata, Languages, and Programming*, part II, pages 403-415, 2012.
- [3] L. Barenboim. Deterministic $(\Delta + 1)$ -Coloring in Sublinear (in Δ) Time in Static, Dynamic, and Faulty Networks. In *Proc. of the 34th ACM Symp. on Principles of Distributed Computing*, pages 345 -354, 2015.

- [4] L. Barenboim, and M. Elkin. Sublogarithmic Distributed MIS Algorithm for Sparse Graphs using Nash-Williams Decomposition. In *Proc. of the 27th ACM Symp. on Principles of Distributed Computing*, pages 25–34, 2008.
- [5] L. Barenboim, and M. Elkin. Deterministic Distributed Vertex Coloring in Polylogarithmic Time. In *Proc. 29th ACM Symp. on Principles of Distributed Computing*, pages 410-419, 2010.
- [6] L. Barenboim, and M. Elkin. Distributed Deterministic Edge Coloring using Bounded Neighborhood Independence. In *Proc. of the 30th ACM Symp. on Principles of Distributed Computing*, pages 129 - 138, 2011.
- [7] L. Barenboim, and M. Elkin. Combinatorial Algorithms for Distributed Graph Coloring. In *Proc. of the 25th International Symp. on Distributed Computing*, pages 66 - 81, 2011.
- [8] L. Barenboim, M. Elkin, and C. Gavoille. A Fast Network-Decomposition Algorithm and its Applications to Constant-Time Distributed Computation. In *Proc. of the 22nd International Colloquium on Structural Information and Communication Complexity*, 2015.
- [9] L. Barenboim, M. Elkin, and F. Kuhn. Distributed $(\Delta+1)$ -Coloring in Linear (in Δ) Time. *SIAM Journal on Computing*, 43(1): 72-95, 2014.
- [10] F. Kuhn, and R. Wattenhofer. On the complexity of distributed graph coloring. In *Proc. of the 25th ACM Symp. on Principles of Distributed Computing*, pages 7–15, 2006.
- [11] N. Linial. Distributive graph algorithms: Global solutions from local data In *Proc. of the 28th Annual Symp. on Foundation of Computer Science*, pages 331–335, 1987.

SIROCCO 2015 Review

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The 22nd International Colloquium on Structural Information and Communication Complexity (SIROCCO 2015) was held on July 15-17 in Montserrat, Spain. The conference took place in a lovely location on the mountain Montserrat (approximately one hour trip from Barcelona).

There were 78 submissions to the conference of which 30 papers were accepted. During the three days of the conference the program also included six keynotes from Michel Raynal, Miquel Angel Fiol, Nati Linial, Saket Navlakha, Bernhard Haeupler, and Amos Korman. The papers “Under the Hood of the Bakery Algorithm: Mutual Exclusion as a Matter of Priority” [10] by Katia Patkin and Yoram Moses and “Randomized OBDD-Based Graph Algorithms” [3] by myself won the Best Student Paper Awards. Before I start with the review, I would like to thank the Program Committee, Organizing Committee, and the Steering Committee for conducting this very good and enjoyable conference where I met many nice people and had a lot of fun.

Clearly, this review cannot cover everything presented during the conference and contains only selected talks to give a rough summary overall.

1 First Day

The program started with the SIROCCO Award Lecture on Communication Patterns and Input Patterns in Distributed Computing which was given by Michel Raynal. This award is an annual prize for innovation in distributed computing and is given to researchers who made a significant contribution on the understanding of the relationship between information and efficiency in distributed computing. In his talk, Michel presented the notion of patterns in either communication messages exchanged by distributed processes or in input data. In terms of input data, Michel showed “good” patterns such that the imported consensus problem on such instances is solvable, which is impossible in general asynchronous distributed systems. He also presented communication patterns related to causality-based problems that can occur due to the causality relation (created by messages) among the events of the processes.



Figure 1: Mountain view

The first paper session of the day was about network algorithms. Juho Hirvonen talked about the power of node labels in local decision problems [6]. They were able to characterize “large” and “small” labels such that large labels provide as much information as unique identifiers do whereas problems on instances with small labels can be harder than on instances with unique identifiers. In the second talk Joel Rybicki showed that the number of communication rounds to find a proper 3-coloring is precisely $\frac{1}{2} \log^* n$ in a graph with n nodes for infinitely many n .

The topic of the second session was scheduling. In “Scheduling Multipacket Frames with Frame Deadlines” [8] each frame consists of packets that arrive online and have to be selected for transmission. The task is to schedule the frames such that their deadlines are met. In the talk I heard that it is possible to construct polylog competitive algorithm in general and constant competitive algorithms for two special cases where the number of packets per frame and the arrival times of the frame packets are restricted. An interesting result on online scheduling with interval conflicts [2] was presented by Pawel Schmidt. In this scenario we have a set U of consecutive integers and a set of intervals in U representing conflicts. The objective is to find a set of integers from U such that there are no two integers within a conflict interval and the size of this set is maximized. They presented a simple randomized priority based algorithm with competitive ratio of $O(\log \sigma / \log \log \sigma)$ that breaks the known $\Omega(\log \sigma)$ lower bound for deterministic algorithms.

The last two sessions of the day were about approximation algorithms and wireless networks. In the area of rumor spreading there was an interesting talk about target selection in social networks [5]. In this setting, the input is a graph $G = (V, E)$ with thresholds $t : V \rightarrow \mathbb{N}$ and costs $c : V \rightarrow \mathbb{N}$ and the problem is to find a set $S \subseteq V$ with minimum cost $\sum_{v \in S} c(v)$ such that the entire graph get influenced by the set S (after some iterations). Here, in each iteration a node u get influenced by his neighbors if the number of influenced neighbors is at least $t(u)$. They further generalized



Figure 2: The social event was an organ concert in this basilica.

this model to partially influenced nodes where each node v has an initial influence level $inf(v)$ that decreases the threshold of the node to $t(v) - inf(v)$. Now, the problem is to find values of $inf(v)$ for every v such that the sum of influences $\sum_{v \in S} inf(v)$ is minimized and the entire graph gets influenced in the end. For these problems they showed inapproximability results (unless $NP \subseteq DTIME(n^{polylog(n)})$) but also provided some polynomial time algorithms with bounded costs (independent of the optimal value) that yielded better results than known heuristics in their experiments. Leonid Barenboim presented the paper “Nearly Optimal Local Broadcasting in the SINR Model with Feedback” [1]. In the SINR model the success of the transmission of a message is dependent on the signal strength and the noise produced by the neighbored nodes. In the local broadcasting problem we want to find a schedule such that each node successfully transmits a message to all his neighbors. They improved the running time for the local broadcasting problem from $O(\Delta + \log^2 n)$ to $O(\Delta + \log n \log \log n)$ which is nearly optimal in view of the lower bounds $\Omega(\Delta)$ and $\Omega(\log n)$ where Δ is the maximum size of a neighborhood in the graph.

The social event of the conference was an organ concert in the Basilica of Montserrat (see Fig. 2). The concert was dedicated to the conference participants and it was one of the highlights of the conference. The organist played an improvisation on the Graph Theory Hymn which was originally created for Czechoslovak graph theory¹.

¹The entire history of the hymn can be found at http://cam.zcu.cz/~ryjacek/publications/hymn_hist_a.html.

2 Second Day

The day started with an invited talk by Nati Linial about random simplicial complexes. The key idea is to have an analogue of Erdos-Renyi graphs in higher dimensions. Since the theory of hypergraphs (as an example of high-dimensional graphs) is not so well understood as the theory of graphs, Nati showed that a small modification of the definition of hypergraphs lead to simplicial complexes where we can use a rich body of powerful tools from topology and geometry that can help. A simplicial complex is a collection X of subsets of nodes that satisfies the following condition: if $A \in X$ and $B \subseteq A$ then $B \in X$. A subset $A \in X$ is called simplex or face with dimension $|A| - 1$. The dimension of X is the largest dimension of a face in X . Then a one dimensional simplicial complex is equivalent to a graph: faces with dimension 0 are nodes and faces with dimension 1 are edges. Nati described how to model random simplicial complexes to study extremal problems on them. For instance, the question “When is a random simplicial complex connected?” is not easy to answer because the notion of connectivity in higher dimensions can be defined in many possible ways. This was a very interesting and entertaining talk where the topic was completely new for me.

In the session on information spreading I heard a talk on “On Fast and Robust Information Spreading in the Vertex-Congest Model” [4]. In this model each node v of a graph has a message m_v and is allowed to send a message of bounded size to all his neighbors in every round. In addition, the nodes can fail independently with a failure probability in each round and a node never recovers after failing. In the end, each node should know the information of all other nodes in the graph. The question is how to choose the forwarded message in each round to minimize the number of rounds until the information is spread. Surprisingly, they showed that it is not a good idea to choose uniformly at random from the messages a node knows and has not forwarded yet. Rather, it is better prioritize unpopular (in terms of the number of times they received a message) towards popular messages. The last session of the day was about mobile nodes and agents. The talk on “Treasure Hunt with Advice” [9] discussed the advice complexity of an online version of the shortest path problem where an agent starts a node s of an unknown graph and wants to reach a node t . The agent only sees the identifiers of the nodes in neighborhood (including the node he is located in) and the weights of the incident edges. Now, the agent has an advice tape containing a string that gives some information on the input instance. They investigated the relationship between the size of the advice string and the competitive ratio that can be obtained. They were able to show that the size of the advice string is $\Theta(n/r)$ for a competitive ratio r .

3 Third Day

The third day started with my favorite talk of the conference by Bernhard Haeupler with the title “Distributed Algorithms for Near-Planar Networks: Low-Congestion Shortcuts” [7]. Bernhard discussed that it was not known how we can facilitate a near-planar structure of graphs to solve distributed optimization problems. He presented recent results on tools like distributed planar embeddings and low-congestion shortcuts. In the latter we have a planar graph $G = (V, E)$ with n nodes and diameter D and disjoint node sets V_1, \dots, V_k . Then we can compute edge sets E_1, \dots, E_k such that for each i the graph $G[V_i] + E_i$ has diameter at most $D \log D$ and each edge of G appears in at most $D \log D$ edge sets. Having this tool, it is straightforward to implement a distributed version of the well-known algorithm by Boruvka for computing the minimum spanning tree: Start with



Figure 3: Participants of SIROCCO 2015

singleton components. Repeat $O(\log n)$ times: Each component adds cheapest outgoing edge. Now, we merge the components by computing the low-congestion shortcuts first and then using these edges to communicate the merge process in time $O(D \log D)$. This leads to a distributed algorithm computing the MST in $\tilde{O}(D)$ rounds in planar graphs which avoids the known general lower bound of $\tilde{\Omega}(\sqrt{n})$ rounds in the distributed setting. Bernhard's talk was quite inspiring and he was able to present the concept and proof ideas in a remarkable way. One of the last talks I heard on the conference was one of the best student papers presented by Katia Patkin. The topic was "Under the Hood of the Bakery Algorithm: Mutual Exclusion as a Matter of Priority" [10]. She analyzed the so-called Bakery algorithm by Lamport which solves the mutual exclusion problem where a process can enter a critical section (CS) such that all others processes are not allowed to enter the CS until the process leaves it. Thereby, every algorithm for the mutual exclusion problem induces a priority relation on the processes. Analyzing this relation can point to unnecessary blocking and waiting in the algorithm. By analyzing this relation of the Bakery algorithm, they were able to improve the algorithm, which they called Boulangerie, that does not suffer from unnecessary blocking.

4 Conclusion

In retrospect, the conference was very well organized, the weather was perfect, and the talks were very good. I was surprised of the quality of the invited talks and learned a lot during this time. This was my first time at SIROCCO and I really enjoyed it. The next SIROCCO will take place in Helsinki, Finland, in July 2016.

References

- [1] Leonid Barenboim and David Peleg. Nearly optimal local broadcasting in the SINR model with feedback. In Christian Scheideler, editor, *Structural Information and Communication Complexity*, volume 9439 of *Lecture Notes in Computer Science*, pages 164–178. Springer International Publishing, 2015.
- [2] Marcin Bienkowski, Artur Kraska, and Pawel Schmidt. A randomized algorithm for online scheduling with interval conflicts. In Christian Scheideler, editor, *Structural Information and Communication Complexity*, volume 9439 of *Lecture Notes in Computer Science*, pages 91–103. Springer International Publishing, 2015.
- [3] Marc Bury. Randomized OBDD-based graph algorithms. In Christian Scheideler, editor, *Structural Information and Communication Complexity*, volume 9439 of *Lecture Notes in Computer Science*, pages 254–269. Springer International Publishing, 2015.
- [4] Keren Censor-Hillel and Tariq Toukan. On fast and robust information spreading in the vertex-congest model. In Christian Scheideler, editor, *Structural Information and Communication Complexity*, volume 9439 of *Lecture Notes in Computer Science*, pages 270–284. Springer International Publishing, 2015.
- [5] Gennaro Cordasco, Luisa Gargano, AdeleA. Rescigno, and Ugo Vaccaro. Optimizing spread of influence in social networks via partial incentives. In Christian Scheideler, editor, *Structural Information and Communication Complexity*, volume 9439 of *Lecture Notes in Computer Science*, pages 119–134. Springer International Publishing, 2015.
- [6] Pierre Fraigniaud, Juho Hirvonen, and Jukka Suomela. Node labels in local decision. In Christian Scheideler, editor, *Structural Information and Communication Complexity*, volume 9439 of *Lecture Notes in Computer Science*, pages 31–45. Springer International Publishing, 2015.
- [7] Mohsen Ghaffari and Bernhard Haeupler. Distributed algorithms for planar networks II: Low-congestion shortcuts, MST, and min-cut. In *SODA*, 2016. to appear.
- [8] Lukasz Jez, Yishay Mansour, and Boaz Patt-Shamir. Scheduling multipacket frames with frame deadlines. In Christian Scheideler, editor, *Structural Information and Communication Complexity*, volume 9439 of *Lecture Notes in Computer Science*, pages 76–90. Springer International Publishing, 2015.
- [9] Dennis Komm, Rastislav Kralovic, Richard Kralovic, and Jasmin Smula. Treasure hunt with advice. In Christian Scheideler, editor, *Structural Information and Communication Complexity*, volume 9439 of *Lecture Notes in Computer Science*, pages 328–341. Springer International Publishing, 2015.
- [10] Yoram Moses and Katia Patkin. Under the hood of the bakery algorithm: Mutual exclusion as a matter of priority. In Christian Scheideler, editor, *Structural Information and Communication Complexity*, volume 9439 of *Lecture Notes in Computer Science*, pages 399–413. Springer International Publishing, 2015.

PODC 2015 Review

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The 34th 2015 ACM Symposium on Principles of Distributed Computing (PODC '15) was held on July 21-23, 2015, in Donostia-San Sebastián, Spain. The main conference and workshops took place at *Miramar Palace*, which sits on a small hill right across the La Concha bay and has a magnificent view of the beach. It is quite an experience to enjoy the beautiful beach after the talks. We start this year's review with birthday celebration, award ceremony, and business meeting, and then I summarize three inspiring keynotes. Finally, I review some talks that I found interesting and insightful.¹ I apologize in advance for talks that are not mentioned due to space limitations.



Figure 1: Magnificent view outside of Miramar Palace. The PODC community was enjoying coffee break and the sunshine!

Birthday Celebration, Doctoral Dissertation Award Ceremony and Business Meeting

- *Alexander A. Shvartsman: 60th Birthday Celebration:*

Chryssis Georgiou gave a touching introduction on Alexander Shvartsman's impacts and mentoring, and showed a video clip of birthday wishes from many prominent researchers around the globe to Alexander. Chryssis briefly described Alexander's influential works including robust distributed cooperation, robust distributed storage, formal verification and specification

¹Some of the talk summaries include open problems that are not mentioned in the papers.

of distributed systems, and electronic voting technology. Chryssis also showed appreciations of Alexander's mentoring.

Alexander shared his experiences and good memory with the community, and discussed his recent contribution on electronic voting technology. Finally, he urged our community to contribute to practical applications. Quoting the concluding remarks from his presentation slides: "*Collectively we can and we should do more: foundations, applications, and outreach*".

- *Doctoral Dissertation Award Ceremony* :

The Doctoral Dissertation Award in Distributed Computing 2015 was awarded to Dr. Leonid Barenboim who completed his thesis *Efficient Network Utilization in Locality-Sensitive Distributed Algorithms*. Leonid is now a faculty member at Mathematics and Computer Science department at the Open University of Israel.

- *Business Meeting*: I summarize some statistics and the highlights from the business meeting.
 1. Among 191 regular papers submissions, 45 papers were accepted, and among 20 brief announcements submissions, 10 were accepted.
 2. There were 140 participants, among which 34 were students.
 3. The community discussed about the possibility of co-locating with other conferences in the future, such as SPAA or STOC.
 4. The community also discussed about PODC reviewing model and the format of brief announcements. For example, whether sub-reviewers should be able to see the other reviews or whether we should have poster-session-like format for brief announcements.
 5. PODC 2016 will be held in Chicago, USA.
 6. Nitin H. Vaidya was elected as the steering committee chair for 2015-2018.

Keynotes

- *Cortical Computation* by Christos Papadimitriou

Christos Papadimitriou gave the first keynote on computational research about the brain. As a motivation, Christos began the talk by addressing how people have used computer science as a point of view to understand other sciences and the world. He then presented several examples including how to model the evolution of sexual population as a repeated game between genes. The focus of the talk was introducing a novel operation *Predictive Join*, or *PJoin* in the *neuroidal* model proposed by Leslie Valiant [8, 9]. Christos discussed how PJoin enables a spontaneous form of unsupervised learning and addressed some potential research directions including understanding how humans learn languages. More concretely, can we identify the primitives in the neuroidal model for learning and identifying grammars?

- *The Mobile Adversary Paradigm in Distributed Computation and Systems* by Moti Yung

Moti Yung began the keynote by reviewing some prior work. In particular, Moti mentioned that mobile adversary research is mainly inspired by two observations: (i) mobile faults originate in systems corruption scenarios such as virus injection, (ii) under managed system, processors would ideally be recovered due to adversary control or self-stabilization mechanisms

(note that usually these mechanisms would not be able to detect all the virus or prevent the virus from gaining control of non-local machines).

In the mobile adversary model, *mobility* is added – that is, the protocol remains secure as long as in each period, enough redundant machines are alive, and faulty machines may be recovered in later periods. This extension introduces a time dimension beyond the space dimension (or redundancy) considered in the traditional literature. Moti then described protocols that provided *proactive security* – the system is correct and safe at any point of time by performing self-recovery, self-healing, and self-re-randomization in a proactive fashion.

In conclusion, Moti urged the community to explore various areas to inspire novel and useful assumptions, models, constructions or proofs. Also, he pointed out that as cyber-attacks become more dynamic and prevalent, the mobile adversary paradigm helps construct a secure system.

- *Online Resource Leasing* by Friedhelm Meyer auf der Heide

Friedhelm Meyer auf der Heide first presented an inspiring observation that many markets have shifted from buying to leasing, and gave an example scheduling problem in the cloud to inspire three main research questions: (i) when should the cloud lease new machines? (ii) which lease period does each leased machine belong to? (iii) how to schedule the tasks to the leasing machine? Then, Friedhelm introduced the standard resource leasing model by walking through the parking permit problem [7], and generalized the model with the notion of deadline (or lease period) – that is, demands (of machines) can be delayed up to some fixed period. The goal is to satisfy all demand deadlines while minimizing the total leasing costs. Friedhelm described two online algorithms in recent work [4, 6]. Finally, Friedhelm concluded with a potential research question on whether it is appropriate and interesting to use game theory to model sellers' perspective.

Regular Papers

Day I: First day, we had many exciting works on network and routing problems, radio networks, and modeling biological behaviors.

- Mohsen Ghaffari won the best student paper award and gave a unique presentation – over Skype.² In spite of the time-zone difference, Mohsen delivered an exciting talk. I'm very fortunate to invite Mohsen to summarize their work and share insights on open problems. The following paragraphs are written by Mohsen.

The paper's focus is on the following basic question about scheduling distributed algorithms: we are given (independent) distributed algorithms A_1, A_2, \dots, A_k on a network graph $G = (V, E)$ and we want to run all of these algorithms together in the shortest span of time possible. For simplicity, assume a synchronous message passing model where per round one (bounded-size) message can be sent along each edge.

Let D (standing for *dilation*) be the maximum round complexity among algorithms A_1, \dots, A_k , and let C (standing for *congestion*) be the maximum number of messages that need to go through one edge, in total over all the algorithms. Then, clearly both dilation (D) and congestion (C) are lower bounds on the time needed for running all the algorithms together, and thus

²Due to visa issue, poor Mohsen could not join PODC '15 in person.

so is $(D+C)/2$. The paper shows a distributed algorithm that computes a schedule of length $O(C + D \log n)$ rounds for running all the algorithms, after $O(D \log^2 n)$ pre-computation rounds. The paper also shows this schedule length to be nearly-optimal by providing a probabilistic method construction of a hard instance in which no schedule can be shorter than $O(C + D \log n / \log \log n)$ rounds.

Open Question: The results in the paper show how to schedule k given independent distributed algorithms near-optimally. A more general question to ask, when considering the broader picture, is that given k independent distributed problems P_1 to P_k , how can we solve all of them together as fast as possible. Using the scheduling results stated above, we can formally say that this question is, up to at most a logarithmic factor, the same as the following more concrete question: given k independent distributed problems P_1 to P_k , design distributed algorithms A_1 to A_k such that the measure $O(C + D \log n)$ is minimized. This question calls for studying the trade-off between congestion (C) and dilation (D). The simplest case of this trade-off, when $k = 1$, is already a rather deep and interesting challenge: given each distributed problem P , we need to characterize the trade-off between the time complexity of each algorithm A for problem P and the maximum over all edges of the number of the messages that A sends through each edge.

- Othon Michail presented their work on developing a model (*solution automata*) that uses algorithmic laws to explain physical or biological systems. This not only reveals the computational aspects of the physical or biological systems, but also allows us to build artificial systems inspired by these systems. One of the main results is that universal constructors allow the automata (or nodes) to self-organize into arbitrarily complex shapes w.h.p. Also, the nodes always terminate. These constructors are based on a terminating protocol for counting the size of the system w.h.p.
- Tsvetomira (Mira) Radeva presented their work on modeling how *Temnothorax* ants hunt for nests. In the house-hunting problem, there are n ants hunting for k candidate nests, where each nest has a binary quality metric, and in the end, ants reach consensus on a single final nest choice. Mira described two algorithms in their model: (i) the first algorithm is optimal but not as natural, since it requires synchrony in each phase of the algorithm and the exact counting of the number of ants in a nest; (ii) the second algorithm adopts natural and simple rules and comes with an extra factor of k (number of candidate nests). In conclusion, Mira proposed many interesting open problems, including relaxing assumptions such as non-binary nest quality, noise in counting or sensing, and variation of each ant.
- Valerie King gave an interesting talk on constructing a minimum spanning forest (MST) and a spanning forest (ST) in the CONGEST model with an undirected communication network with n nodes and m edges. They proposed Monte Carlo algorithms finding MST and ST using $O(n \log^2 n / \log \log n)$ and $O(n \log n)$ messages, respectively, w.h.p. These results contradict the folk theorem noted in [1], which stated that the distributed construction of a broadcast tree requires $\Omega(m)$ messages. One reason that their algorithms circumvent the lower bound is by assuming an exponential bound on the size of the identity space in the KT_1 model, where each node knows its own identity and the identities of its neighbors.

In the end of the talk, Valerie mentioned many open problems, including (i) is $\Omega(m)$ communication required for building tree in asynchronous model? (ii) algorithms exploring the

trade-off time and communication complexities.

- Calvin Newport gave a lively presentation on a (truly) local broadcast layer. He first motivated the audience by discussing how some early MAC research depends on the assumption that nothing ever changes (in the network). Calvin then described their implementation of the efficient local broadcast service in the dual graph radio network model where topology may change over time. The implementation is *truly local*, which means the time complexity and error bounds are independent of global parameters, e.g., network size. Their implementation is based on three *big ideas* (as emphasized by Calvin): (i) reducing contention in radio model is easy, (ii) changing your behavior on the fly when the network graph is determined, (iii) contention decomposition in large network helps.

In addition to the main results, I found two interesting take-aways from the talk: in the era of Internet-of-things, it is important to design (truly) local algorithms, and unpredictability (e.g., dual graph model) opens up exciting theoretical problems.

- Boaz Patt-Shamir presented their work on approximate distributed solutions to the weighted all-pairs-shortest-paths (APSP) problem in the CONGEST model. Their results rely on a key algorithmic tool – a generalized (S, h, σ) -detection problem [5]. The novel idea in this work is an algorithm that outputs an approximate solution to (S, h, σ) -detection in weighted graphs. One of the coolest notes from this talk is that Boaz presented a result that is better than promised (in the PODC paper) due to a new result on arXiv (which just came out before PODC '15). Boaz concluded the talk by pointing out an open problem: exact APSP in $O(n)$ time.

I have reached out to Boaz, and he kindly pointed me to the arXiv paper by Henzinger, Krininger and Nanongkai [3]. Boaz mentioned that using the algorithm from [3] as a black box, they could simplify and obtain improved running time in their construction of compact routing tables.

Day II: We had many exiting works on shared memory, transactional memory and security protocols. We also had a great touring before the delicious conference banquet in the end of the day. We were lucky that the rain let up when we enjoyed the tour of the old town of San Sebastián.

- Hagit Attiya presented their work on exploring the trade-off between number of fences and number of RMR (Remote Memory References) when writes can be reordered. The most interesting take-away is the proof strategy: unlike traditional approaches that construct an execution that requires the lower bound, this work adopts an information theoretic argument, i.e., constructing *a set* of executions, then arguing that at least one of them needs so many messages. Hagit also mentioned that the trade-off also applies to many ordering problems in cache-coherent and distributed shared memory architectures.
- Zahra Aghazadeh talked about their work on time and space complexity for detecting and preventing ABAs in shared memory algorithms, where the ABA problem is defined as: Even though a process reads the same value twice in a row from a shared object, it is still possible that the value of the object has changed multiple times. They introduced a new type of register – ABA-detecting register – which is basically the read-write register plus the ability to detect if the ABA problem happens. They proved that any shared object that detects

the ABA problem is inherently hard, i.e., it is not easier than implementing a load-linked store-conditional (LL/SC) object (in terms of time-space trade-off).

Zahra concluded the talk with two interesting open problems: (i) Does randomization improve the time-space trade-off? (ii) Is it the case that implementation of any ABA-detecting register from any objects requires at least n bits, where n is the number of processes in the system?

- Shahar Timnat gave one of the most well-presented talk on their paper – Help! – which formally studies the *helping* mechanism. Roughly speaking, in this mechanism fast processes help slow processes complete their operations. There are some data types that cannot provide wait-freedom without a helping mechanism, i.e., there is no linearizable wait-free and help-free implementations for these data types, including (i) *exact order types*: the order between two operations matters, i.e., changing the order of a pair of operations affects future operations (e.g., FIFO queue), and (ii) *global view types*: it supports an operation that returns some form of a global view (e.g., a single-scanner snapshot).

I found the related open questions quite interesting, because the answers would reveal more inherent properties of wait-freedom: (i) Are there other definitions of helping mechanism? If yes, how are they related to each other? (ii) Is there a more general characterization of data types that require helping mechanism to obtain wait-freedom?

- Björn Tackmann talked about their work on two-party communication that is optimal in *fairness*. The fairness of interest is defined in the context of distributed cryptographic protocols – if the adversary learns the output, all honest parties also learn the output. The authors relaxed fairness guarantees using a utility-based approach. Intuitively, the relaxed fairness is based on two notions: (i) the utilities for the individual outcomes define an expected payoff for each strategy chosen by the adversary, and (ii) a protocol is *fairer* if the expected payoff of the *best* adversary strategy is smaller. Björn also presented a two-party protocol that achieves the optimal fairness for computing any given function. The result can be extended to multi-party computation of non-reactive functions. One open problem mentioned in the talk is the exact characterization of multi-party protocols of general functions.
- Carmit Hazay presented their protocols that tolerate an *adaptive adversary*, which could choose the parties to corrupt dynamically. Traditionally, there were two types of protocols: *adaptive with erasures*, where the honest parties may erase intermediate data (so that the adversary will not be able to learn the data), and *adaptive without erasures*, where no such erasing mechanism exists. While the second mechanism seems harder, the assumption of secure erasure in the first mechanism is non-trivial and unrealistic due to physical limitations in some cases. Carmit presented their new notion of secure protocols – *adaptive security with partial erasures* – which uses erasures in a *minimal sense*. One of the key theorems proves that the following are all equivalent under semi-honest and malicious adversaries: (i) There exists an OT (Oblivious Transfer) protocol that is semi-adaptively secure; (ii) There exists an OT protocol that is adaptively secure with partial erasures; (iii) There exists an OT protocol that is adaptively secure without any erasures. Moreover, they showed computation ensuring adaptive security with partial erasures is as efficient as static secure computation. Carmit concluded the talk by pointing out two open problems: constant round two-party computation with partial erasures and extension to multi-party computation.

Day III: During the last day, we had a diverse range of topics, including work on coloring, consistency, gossip protocols, and fault-tolerance.

- Leonid Barenboim gave a lively presentation on their work on $(\Delta+1)$ -coloring in sublinear time (in Δ), which won the best paper award. The main idea is quick coloring of partially-colored subgraphs. He pointed out that two main challenges of this idea are (i) how to compute a partition into few subgraphs with *bounded degree*? (ii) how to *efficiently* compute a proper coloring of a subgraph that is consistent with all previous colorings? Leonid used graphical examples to illustrate their technique. The same technique can be applied to dynamic and faulty graphs (where each vertex may lose the computed solution due to failure).

Leonid concluded with several open questions: (i) lower bounds for coloring problems in this setting, (ii) algorithms for maximal matching and maximal independent set that are sublinear in Δ , (iii) deterministic coloring algorithms in polylogarithmic time.

- Rachid Guerraoui discussed their work on the weakest failure detector for eventual consistency. He first gave a nice introduction of SMR (state-machine replication), and mentioned that most SMR implementations ensure only eventual consistency. This motivates them to explore eventual consistency. They first formally define the notions of eventual consensus and eventual total order broadcast, and extend the CHT proof [2] to prove that with majority of processes being correct, the weakest failure detector to implement an eventually consistent system is still Ω , the same as the one used to implement total order broadcast. This presentation ended with a lively discussion between Rachid and Eli Gafni.
- Adam Morrison presented their work on exploring systems that have practically-inspired properties, including high availability (response without communication), ensuring causal consistency and non-sequential objects – Multi-Valued Register (MVR) – which allows a read to return the set of values written by all conflicting writes. The main motivation for using MVR is to expose conflicts to users so that users can exploit domain knowledge to resolve the conflict. They proved that the strongest consistency model that can be achieved by their model is Observable Causal Consistency (OCC), which is somewhat stronger than causal consistency, and intuitively captures executions in which client observations can use causality to infer concurrency of operations. Adam mentioned that the consistency result is *not* tight, and the tight result is an interesting future work.
- Merav Parter presented their work on breadth-first search (BFS) structures that tolerate up to two edge failures, i.e., after removing up to two edges, the resulting graph contains a BFS spanning tree. For the single source case in unweighted undirected graphs, Merav showed that $\Theta(n^{5/3})$ is the tight bound on edges to build a dual failure resilient BFS structure. The lower bound part can be extended to the general case for tolerating more than two edge failures. In the end, Merav mentioned several open problems: (i) the multiple sources case for two failures (the lower bound part can be derived from the results in this paper, but the upper bound part is a bit tricky), (ii) the problem on directed graphs, and (iii) an upper bound for any number of faults.
- Dahlia Malkhi gave a great presentation on their work on distributed resource discovery. In the resource discovery problem, there are n machines, and the system is assumed to be synchronous. At any timestep, each machine v can PUSH or PULL a message to/from any

other machine u whose IP address is known to v . The goal is for all machines to learn the addresses of all other machines as fast as possible with small number of messages sent (polynomial in n). Prior work proposed the optimal algorithm for (initial) networks with a linear (or polynomial) diameter. They proposed a randomized distributed algorithm that runs in $O(\log D \log \log n)$ rounds using $O(n)$ messages, where D is the strong diameter of the initial network. In particular, their algorithm almost achieves an exponential speedup in a graph with polylogarithmic diameter.

Dahlia presented several tools used in the paper, including forming clusters of nodes, discovering clusters' neighbors, and finding more neighbors using degree inflation. Dahlia concludes the talk with two open problems: (i) a gossip algorithm in which each machine sends at most one message per round, (ii) an optimal gossip algorithm for resource discovery problem.

- I presented our work on fault-tolerant consensus in directed graphs. I mentioned *tight* necessary and sufficient conditions on the underlying communication graphs for solving three consensus problems: (i) exact crash-tolerant consensus in synchronous systems, (ii) approximate crash-tolerant consensus in asynchronous systems, and (iii) exact Byzantine consensus in synchronous systems. I presented the algorithm for achieving exact consensus in synchronous system with crash faults, and sketched the necessity and sufficiency proofs.

I concluded the talk with two main open problems: (i) tight condition for approximate Byzantine consensus in asynchronous systems, and (ii) given a graph G , the hardness of checking whether G satisfies the conditions identified in our paper.

References

- [1] B. Awerbuch, O. Goldreich, R. Vainish, and D. Peleg. A trade-off between information and communication in broadcast protocols. *J. ACM*, 37(2):238–256, Apr. 1990.
- [2] T. D. Chandra and S. Toueg. Unreliable failure detectors for reliable distributed systems. *J. ACM*, 43(2):225–267, Mar. 1996.
- [3] M. Henzinger, S. Krininger, and D. Nanongkai. An almost-tight distributed algorithm for computing single-source shortest paths. *CoRR*, abs/1504.07056, 2015.
- [4] P. Kling, F. Meyer auf der Heide, and P. Pietrzyk. An algorithm for online facility leasing. In G. Even and M. Halldórsson, editors, *Structural Information and Communication Complexity*, volume 7355 of *Lecture Notes in Computer Science*, pages 61–72. Springer Berlin Heidelberg, 2012.
- [5] C. Lenzen and D. Peleg. Efficient distributed source detection with limited bandwidth. In *Proceedings of the 2013 ACM Symposium on Principles of Distributed Computing*, PODC '13, pages 375–382, New York, NY, USA, 2013. ACM.
- [6] S. Li, A. Mäcker, C. Markarian, F. Meyer auf der Heide, and S. Riechers. Towards flexible demands in online leasing problems. In D. Xu, D. Du, and D. Du, editors, *Computing and Combinatorics*, volume 9198 of *Lecture Notes in Computer Science*, pages 277–288. Springer International Publishing, 2015.

- [7] A. Meyerson. The parking permit problem. In *Foundations of Computer Science, 2005. FOCS 2005. 46th Annual IEEE Symposium on*, pages 274–282, Oct 2005.
- [8] L. G. Valiant. *Circuits of the mind*. Oxford University Press, 1994.
- [9] L. G. Valiant. Memorization and association on a realistic neural model. *Neural Comput.*, 17(3):527–555, Mar. 2005.

DISC 2015 Review

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The conference took place at Hosei University, on the 26th floor of the Boissonade Tower, featuring a breathtaking view of Tokyo. The first day of the conference started with a keynote talk given by Thomas Moscibroda. The talk focused on the intersection of theory and practice, and the way practical considerations and theoretical insights are combined together to tackle high-impact problems that arise at the largest scale: where to look for improvements, how seemingly small optimizations can be major difference-makers, and how simple, clever approaches often outweigh the benefits of more sophisticated ones. Thomas demonstrated these points with excellent examples based on the experiences at the cloud computing platform at Microsoft. In particular, he described algorithms that were designed and implemented to improve the resource utilization of the cloud, amid a myriad of constraints and complementary metrics. Another example was data layout optimization by ordering database columns, based on analyzing access patterns by the queries. This approach utilized the large amount of data available and the outcomes in both cases were extremely impressive. Even though we heard that in practice, a simple algorithm with few lines of code and good enough performance is almost always more desired than a complex, optimal solution, the talk also demonstrated the importance of intuitions that mainly stem from good theoretical modeling and understanding of the practical distributed systems.

The next talk, given by Benjamin Fish, was about the complexity theory around the MapReduce computation model. He described how the computational power changes with increasing rounds and time, and how the results could be useful for proving relations to established complexity classes, which is a natural open problem.

The following session started by Joel Rybicki presenting a way to improve the recent algorithm of the authors for the counting problem in synchronous networks with Byzantine failures to achieve the optimal resilience. It was followed by two presentations about the beeping model, where the communication of nodes is limited to beeps. Among the considered problems were leader election with optimal size of state space, with implications for the computational power of the model, and synchronization, where the the goal is to converge to all nodes beeping synchronously, like the

lights of fireflies. Next, Oksana Denysyuk gave a talk about interesting separations under strong linearizability. She showed that certain standard objects with linearizable wait-free implementations from registers, are impossible to implement in a strong linearizable and wait-free manner, but possible if the termination condition is relaxed to lock-freedom. The proof involved a neat new notion of group valency. The session was concluded by Jennifer Welch, who presented a simulation of atomic read-write register in an asynchronous message-passing system that tolerates nodes entering and leaving the system without making any assumptions about quiescence.

The next session was kicked off by talks about plane formation by a swarm of mobile robots and graph exploration. In the second half of the session we heard about combining hardware transactional memory and nonvolatile memory, a mechanism for reconfiguring atomic storage systems and automatic lock removal approach that could be applied, for instance, to the lock-based implementations of data-structures with the aim to improve performance to be comparable to the custom-crafted and much more complex lock-free algorithm implementations.

The coffee break was followed by a brief announcement session, covering a range of topics from rumor-spreading and graph exploration to wireless ad hoc networks and ant colonies.

The final session of the day was mainly dedicated to transactional memory. Srivatsan Ravi gave two talks, one where he showed that under some requirements, hybrid transactions (i.e. best-effort hardware transactions with slow software transactions as a backup) must necessarily exhibit an unavoidable amount of instrumentation overhead, and the second talk about a complexity gap between non-blocking and lock-based transactional memory schemes, providing insights into the shift in practice towards the lock-based approach. There was another talk about the hardware transactional memory by Michael Spear, who described a new algorithm and an extensive and useful overview of design considerations. The only talk that was not about transactional memory demonstrated new relations between two commonly used measures for contention: point contention and interval contention.

The day was concluded by a business meeting, where Keren Censor-Hillel and Roberto Baldoni were elected as members of the DISC steering committee. Also, options for open access were discussed, and in particular the fact that the proceedings are now freely available on HAL:<https://hal.archives-ouvertes>. Finally, next year DISC takes place in Paris, and the venue for 2017 was also discussed.

The second day started with two sessions on algorithms in graphs and networks, and continued with a session with two techniques for proving data structures linearization and two methods for dealing with transactions implementation in HTM and in a distributed environment. A tree data structure that is transaction-friendly and performance analysis of lock-free data structures concluded this session. The first session started with the analysis of class of voting processes based on sampling two opinions, presented by Takeharu Shiraga. The next presentation, by Jochen Seidel, introduced a tradeoff between the number of random bits that are required for symmetry breaking and the runtime of the algorithm. Following was a public coin with constant bias implementation, as well as a Byzantine leader election algorithm with $O(\log^3 n)$ round complexity, that were presented by Peter Robinson. Thomas Moscibroda, whose paper with Yuezhou Lv won the best student paper award, concluded this session with a study of different local decision algorithms in social networks.

The second session started with Merav Parter, who observed the problem in wireless networks is to bound information in nodes' neighborhoods and not contention, and in addition proposed a new algorithm for reducing such information. Sebastian Daum described an asymptotically optimal algorithm for calculating MIS in multichannel radio networks. Merav Parter provided a theoretical

justification for engineering practices basing zonal tessellations on the Voronoi diagram. This talk ended the networks and graphs sessions.

In the third session, the first two presentations were about linearization techniques for algorithms with non-trivial linearization proofs. Gregory Chockler managed to prove the linearization for algorithms that accommodate lazy non-synchronized sections, while Nir Hemed managed to compose correctness proofs recursively for dependent histories such as the ones in synchronized queue and elimination stack. The second half of the third session dealt with transaction implementations. Andrea Cerone proposed parallel snapshot isolation (PSI) for reasoning about distributed database transactions. Yehuda Afek introduced amalgamated transactions, a hybrid of hardware and software transactional memory that puts very low overhead on the hardware fast-path. This approach allows efficient use of HTM in applications that previously could not benefit from it. Roberto Palmieri presented an interference-free tree that defers the balancing to a special thread and thus removes overhead and contention from the critical path of insert and delete, which allows the efficient usage of these semantic operations in lock-based transactions. The last presentation of the day proposed a model to predict the performance of lock-free data structures and their best back-off policy according to conflicts, which are split into hardware and semantic conflicts.

After the talks we went on an interesting excursion which included the Imperial Palace grounds, the Asakusa Temple, and a cruise. The day ended at a special restaurant where we had a traditional Japanese dinner with excellent food that came mostly from the sea, and also practiced some DISC traditions as the best papers awards, Dijkstra Prize ceremony and the changing of DISC chair.



Figure 1: Left: View of Imperial Palace grounds. Right: Asakusa Temple.

The last day of the conference opened with the keynote talk by the 2015 Edsger W. Dijkstra Prize winner Michael Ben-Or. He gave comprehensive background on the use of randomization for Byzantine generals problem. Then he reviewed the theory and practice for communication with quantum channels, its implications for the Byzantine generals, and described some intriguing open problems. Next, Rati Gelashvili gave the best paper talk about the optimal space complexity of consensus for anonymous processes. He presented two main ideas, one to re-use the process clones (a term to describe processes in identical states) and another to define valency with regards to particular types of executions, to improve the well-known square root lower bound due to Fich, Herlihy and Shavit to linear number of registers in the anonymous setting. The general case of the problem remains open.

The next session was devoted to brief announcements, several of which were also about anonymous consensus. Leqi Zhu presented a different proof of the linear space anonymous lower bound in a memoryless snapshot model, and a matching consensus upper bound with n registers for n anonymous processes. Zohir, Raynal and Pierre had a similar upper bound combined with a natural extension to the set agreement problem. These results for the first time show that to solve consensus, anonymous processes do not need extra registers, and offer new insights for designing anonymous algorithms. On the other hand, another brief announcement showed that, if we consider uncontended complexity to solve consensus, then anonymous processes are provably less space efficient. Two announcements were related to transactional memory. The first was about concurrently using flat combining and transactional lock elision with hardware transactional memory, and in the second talk, Trevor Brown proposed to add a slower but safer transactional middle path to the standard model with fast transactional path and a slow path with a global lock, and experimental evaluation of the approach.

Ilan Komargodski started the next session by presenting a generic way to compress communication in distributed algorithms, preserving the complexity and resiliency guarantees. In particular, this work implies a connection between the two standard models, congest and local, showing that for certain parameter regimes and local algorithms, they can be made to work in the congest model by essentially compressing their communication. Also in this session, Nupur Mittal described an algorithm for diffusing information that users find interesting in social networks, without revealing any particular user's preferences. Interestingly, the way to achieve this turns out to make probabilistic decisions, sometimes disregarding the user's directive with small probability, for the good of the system and privacy. Later, there were several consecutive talks about algorithms on graphs, including load balancing, independent sets, and fault-tolerant reachability. We particularly liked the smoothed analysis for different tasks like random walks and flooding with respect to the perturbations in the underlying graph, demonstrating a wide range of effects depending on the problem. In the same session, we heard about a generalized notion of linearizability that allows specifying tasks not expressible by sequential specifications.

The first two talks of the last session of the conference were about population protocols. First, David Doty presented a strong lower bound on the convergence time of leader election in population protocols, resolving an important open question of whether fast leader election is possible with constant states. The proof used some interesting tools from the earlier works of the authors, with the high level strategy to show that if the protocol elects the leader sufficiently fast, then it must have sufficiently many certain types of transitions, which can be used to modify the transition sequence and lead to a configuration such that a leader is never elected. The next talk, by Janna Burman, contained several elegant and clever counting algorithms in population protocols using very few states. The last talk at the conference was about dynamic reconfiguration in distributed services and the maintenance of the configurations, without relying on repeated consensus, which is problematic, but instead converging through a sequence of carefully designed proposal-adjustment phases.