



COMPLEXITY
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STOCHASTIC THERMODYNAMICS OF COMPLEX SYSTEMS

ONLINE CSH WORKSHOP REPORT

May 27 – May 29, 2020

COMPLEXITY SCIENCE HUB VIENNA
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Dear workshop attendees, dear colleagues,

We would like to briefly summarize the online workshop entitled 'Stochastic thermodynamics of complex systems' held from 27th to 29th of May 2020, especially for how it might help the community design the second online workshop to take place next year.

In this report, we recap the workshop's scientific program, describe the technical part of the workshop, and provide links to videos from the talks, slide files, articles mentioned during the chat, and other resources that might be interesting. We also briefly describe what we feel to be the advantages and disadvantages of the online format.

We end with the results of the online polls held during the workshop, and a list of some of the papers that were mentioned during the discussions.

With kind regards,

Workshop organizers
David Wolpert
Jan Korbel

Scientific summary

The main aim of the workshop was to study the stochastic thermodynamics of complex systems. **Stochastic thermodynamics** is a powerful tool that can describe the thermodynamics of small non-equilibrium systems. To its main achievements belong **fluctuation theorems**, **thermodynamic uncertainty relations**, and **speed limits**. However, typical assumptions used in ordinary stochastic thermodynamics are **linear Markovian dynamics**, **no constraints on transition rates** (except local detailed balance), **arbitrary work protocols**, **infinite heat baths** (resulting in Boltzmannian local equilibrium states) and **a local detailed balance**. The main question of the workshop was: *How does stochastic thermodynamics - especially the FT, TUR, SL, etc. - change if these assumptions do not hold?*

There were several topics discussed throughout the workshop. The workshop started with the issue of **the Principle of maximum entropy and its role in non-equilibrium thermodynamics**. A gentle introduction to this topic was provided by the session chair *Massimiliano Esposito*. The first speaker of the workshop, *Stefan Thurner*, discussed the Maximum entropy principle for complex systems. The issue was also later mentioned by *Rudolf Hanel*, on the example of systems with emergent structures.

A related issue is the correct definition of **Free energy, entropy, and other thermodynamic potentials** for complex non-equilibrium systems. *Takahiro Sagawa* mentioned the existence of a complete thermodynamic potential for quantum many-body systems. *Phillip Strasberg* discussed the correct definition of entropic functional and introduced the so-called observational entropy. *Artemy Kolchinsky* investigated the maximal extractable work from a system depending on available protocols.

Another related issue is the derivation of **Entropy production bounds** for complex systems. *Naoto Shiraishi* mentioned some bounds stronger than the second law of thermodynamics for finite-speed processes. *Krzysztof Ptaszyński* showed that in open quantum systems, the entropy production comes mainly from the intra-environment correlations. *Paul Riechers* discussed the Error-Dissipation tradeoff when computing with time-symmetric protocols.

A key topic of stochastic thermodynamics is currently **Thermodynamic uncertainty relations (TUR)**. *Yoshihiko Hasegawa* presented TUR for open quantum systems. *Sosuke Ito* discussed a connection of TUR to information geometry. *Udo Seifert* presented a general view on TUR and focused on a model-free version of the relation. *Massimiliano Esposito* presented a generalization of TUR and discussed a dissipation-time version of TUR.

Of the main features of complex systems is the presence of **Non-Boltzmannian equilibrium distributions**. *Jan Korbelt* described the relation between the dynamics of the system and the corresponding entropy functional when the detailed balance and second law are obeyed. *Christopher Jarzynski* showed that when a small, fast system with chaotic behavior is coupled to a large, slow system, the equilibrium distribution of the large system is not Boltzmannian.

In real systems, we face the problem of **restricted control protocols**. This issue was discussed by *David Wolpert* in the case of multipartite systems. *Artemy Kolchinsky* derived the formula for the maximal extractable work when a control protocol is restricted. *Henrik Wilming* mentioned the effect of control restrictions in quantum thermodynamics.

One of the main applications of stochastic thermodynamics is understanding **Thermal engines**. *Michele Campisi* presented the thermodynamics of a quantum annealer. *Keiji Saito* discussed microscopic heat engines from the perspective of information geometry.

As it turns out, **Information geometry** is one of the more prominent mathematical frameworks used in modern stochastic thermodynamics. This was evident from the talks by *Toshihiko Hasegawa*, *Sosuke Ito*, *Keiji Saito*, and others. To this end, *Nihat Ay* discussed the current role of information geometry in stochastic thermodynamics.

The workshop also contained several discussion sessions, where the aforementioned topics were thoroughly discussed.

Technical summary

The whole conference was held in a videoconference software, Zoom. From the technical point of view, the workshop proceeded smoothly, without major technical details. Moderated Q&A sessions and discussion sessions were also smooth, and the flow of the discussion was quite natural.

Advantages and Disadvantages of the online format

Advantages

- The workshop is more inclusive everybody can join it, including grad students, people from the global south etc. – no travel expenses
- Far easier for junior people to connect with senior people – just use chat channel
- Moderator has more control – can ensure nobody monopolizes questions / discussion, that junior researchers and women get to ask questions and participate in discussion, etc.
- More flexible format
- Less of a time commitment by participants
- No expenses with putting on the workshop
- Participants avoid stress / disruption of travel

Disadvantages

- Discussion is constrained (at least, with current videoconferencing software)
- No informal discussions „around the coffee machine “
- You do not get to visit a famous conference venue
- There is no social program (conference dinner, excursions,...)

Participant summary

The workshop consisted of **21** speakers, and other ca **150** non-speaking participants. On the first day, there were **259** Zoom attendees (including multiple accesses), on the second day, there were **204** attendees, and on the third day, there were **143** attendees. The Facebook stream had more than **1000** views aggregated for all three days. Participants were from more than **25** different countries lying over **18** different time zones.

Scientific program

Wednesday, May 27, 2020

12:30 - 13:00 *Testing the connection*
13:00 - 13:10 *Welcome and Introduction*

[slides](#)

Session 1

The role of entropy and maximum entropy principle in non-equilibrium thermodynamics

Chair: M. Esposito

13:10 - 13:15 *Opening remarks*
13:15 - 13:35 Stefan Thurner
13:45 - 14:05 Takahiro Sagawa
14:15 - 14:35 Naoto Shiraishi
Q&A

[video](#)

[slides](#)

[slides](#)

[video](#)

[slides](#)

[video](#)

[slides](#)

14:45 - 15:30 *Discussion session 1*

15:30 – 16:00 *Break*

Session 2

Stochastic thermodynamics for complex systems with very strong coupling among subsystems

Chair: A. Kolchinsky

16:00 - 16:05 *Opening remarks*
16:05 - 16:25 David Wolpert
16:35 - 16:55 Philipp Strasberg
17:05 - 17:25 Massimiliano Esposito
17:35 - 17:55 Krzysztof Ptasiński

[video](#)

[slides](#)

[video](#)

[slides](#)

[video](#)

[slides](#)

[video](#)

[slides](#)

18:05 - 18:45 *Discussion session 2*

Thursday, May 28, 2020

Session 3

Thermodynamic uncertainty relations for complex systems

Chair: T. Sagawa

13:00 - 13:05 *Opening remarks*

13:05 - 13:25 Yoshihiko Hasegawa

[video](#)

[slides](#)

13:35 - 13:55 Sosuke Ito

[video](#)

[slides](#)

14:05 - 14:25 Paul Riechers

[video](#)

[slides](#)

14:35 - 14:55 Udo Seifert

[video](#)

[slides](#)

15:05 - 15:45 *Discussion session 3*

15:45 – 16:15 *Break*

Session 4

Stochastic thermodynamics for non-Boltzmann equilibrium distributions

Chair: D. Wolpert

16:15 - 16:20 *Opening remarks*

16:20 - 16:40 Artemy Kolchinsky

[video](#)

[slides](#)

16:50 - 17:10 Michele Campisi

[video](#)

[slides](#)

17:20 - 17:40 Jan Korbel

[video](#)

[slides](#)

17:50 - 18:10 Christopher Jarzynski

[video](#)

[slides](#)

18:20 - 19:00 *Discussion session 4*

Friday, May 29, 2020

Session 5

Information-theoretic measures for thermodynamics of complex systems

Chair: J. Korbel

13:00 - 13:05 *Opening remarks*

13:05 - 13:25 Keiji Saito [video](#) [slides](#)

13:35 - 13:55 Alec Boyd [video](#) [slides](#)

14:05 - 14:25 Kay Brandner [video](#) [slides](#)

14:35 - 15:10 *Discussion on possibility of an annual virtual workshop*

15:10 - 15:30 *Discussion session 5*

15:30 - 16:00 *break*

Session 6

General features of non-equilibrium thermodynamics for complex systems

Chair: C. Jarzynski

16:00 - 16:05 *Opening remarks*

16:05 - 16:25 Rudolf Hanel [video](#) [slides](#)

16:35 - 16:55 Nihat Ay [video](#) [slides](#)

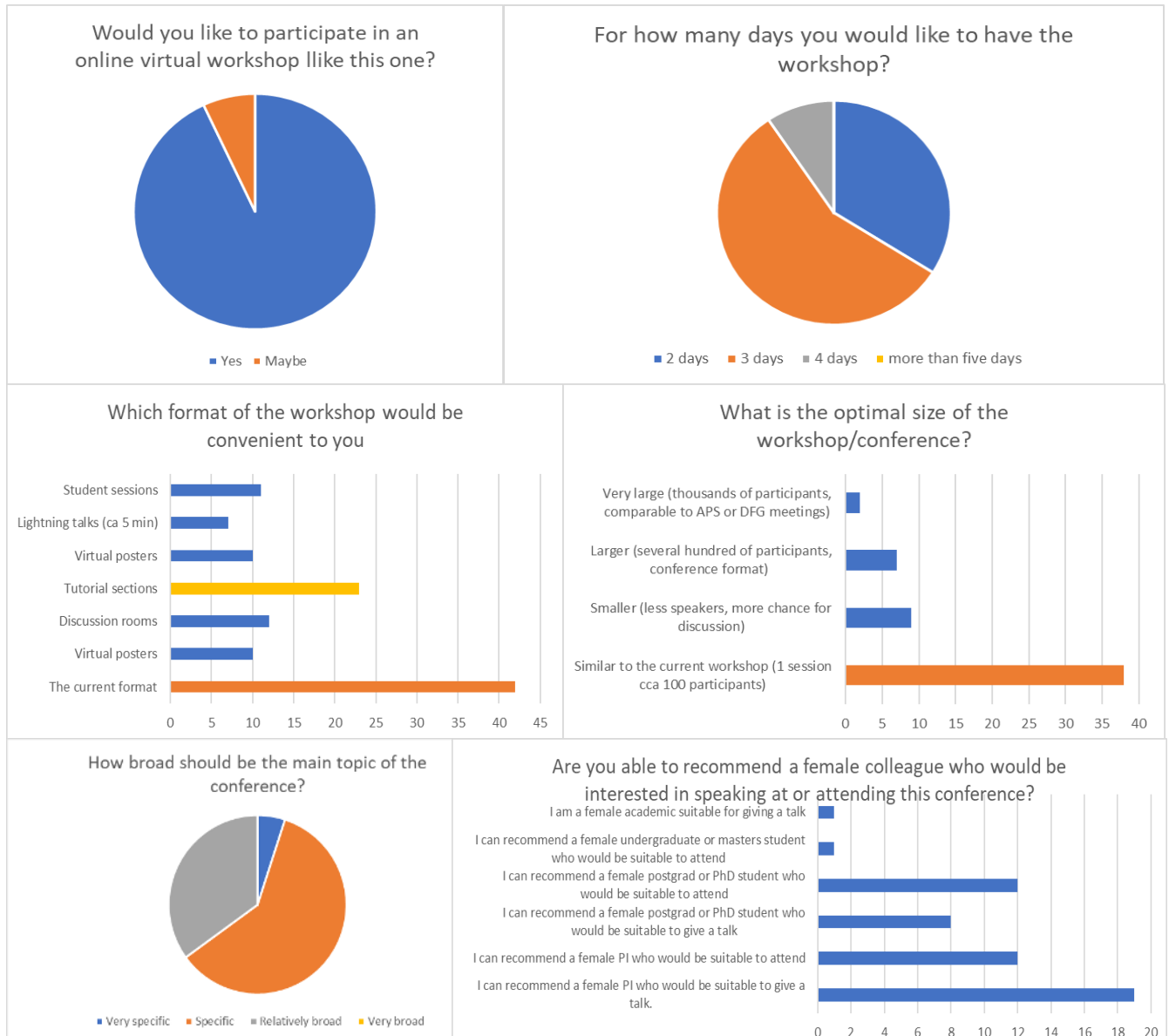
17:05 - 17:25 Henrik Wilming [video](#) [slides](#)

17:35 - 18:00 *Discussion session 6*

18:00 - 18:10 *Closing remarks*

Poll results

During the section when we discussed the possibility of an annual workshop, we have asked several questions via the poll feature in Zoom. Here are the results:



References

Below are listed some references mentioned during the workshop (ordered as appeared in chat):

Chat references:

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C. W. Lynn, E. J. Cornblath, L. Papadopoulos, M. A. Bertolero, D. S. Bassett, Non-equilibrium dynamics and entropy production in the human brain. <https://arxiv.org/abs/2005.02526>

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Workshop Organizers

David Wolpert Santa Fe Institute, External Faculty Complexity Science Hub Vienna,
Arizona State University
Jan Korbel Medical University of Vienna, Complexity Science Hub Vienna

Speakers

| | |
|-----------------------|--|
| Nihat Ay | Max Planck Institute for Mathematics in the Natural Sciences |
| Alex Boyd | Nanyang Technological University |
| Kay Bradner | University of Nottingham |
| Michele Campisi | University of Florence |
| Gavin Crooks | University of California, Berkeley |
| Massimiliano Esposito | University of Luxembourg |
| Rudolf Hanel | Complexity Science Hub Vienna, Medical University of Vienna |
| Yoshihiko Hasegawa | University of Tokyo |
| Sosuke Ito | University of Tokyo |
| Christopher Jarzynski | University of Maryland |
| Artemy Kolchinsky | Santa Fe Institute |
| Jan Korbel | Complexity Science Hub Vienna, Medical University of Vienna |
| Krzysztof Ptaszynski | Polish Academy of Sciences |
| Paul Riechers | Nanyang Technological University |
| Takahiro Sagawa | University of Tokyo |
| Keiji Saito | Keio University |
| Udo Seifert | University of Stuttgart |
| Naoto Shiraishi | Gakushuin University |
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