

Chapter 7

Discrete-Event Simulation Research Team

7.1 Members

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7.2 Research Activities

Computer simulations are now essential for all fields of science and engineering, and indispensable to our society. They extend our ability in theoretical and mathematical description, and accelerate the global development. When a problem is challenged with computer simulation, mathematical models to describe it are prepared and solved with appropriate parameters and conditions using computers. There are two kinds of simulation models: "continuous" models using continuous functions and differential equations, and "discrete" models using discrete objects and case-wise evolution rules. The continuous models are used in, for example, flow simulations with hydrodynamic equations like Navier-Stokes and Euler, electromagnetic simulations with the Maxwell's equations, and elementary-particle simulations with field theoretic models like lattice QCD. Computers calculate and simulate discretized approximation model of these continuous models, and the calculations are often characterized by enormous number of repetitions of regular processing patterns.

The discrete models are used in, for example, particle simulations with event-driven dynamics and discrete-element models, and traffic and processing simulations with agent, queueing, automata and network models. Computers judge whether conditions are fulfilled or not and determine next states, that is, discrete-events.

One characteristic feature of discrete-event simulations is their variety both in model parameters and behaviors. Different parameters of discrete models often result in qualitatively quite different behaviors. For example, two particles just pass through when they do not collide with each other, but they will be scattered to different orbits when they collide. A automaton reacts specifically when their inputs satisfy its activation condition. A system with such discrete elements will behaves unpredictable way. This feature is much different from the case of "continuous" simulations which are often characterized by continuous change in behaviors when input parameters are slightly modified.

Another feature of discrete-event simulations is its network structure. Relations between elements are often characterized by graphs and the graphs have usually nonuniform. For example, in a system of hard particles, colliding particles are connected and noncolliding ones are not. The connection changed at every collision.

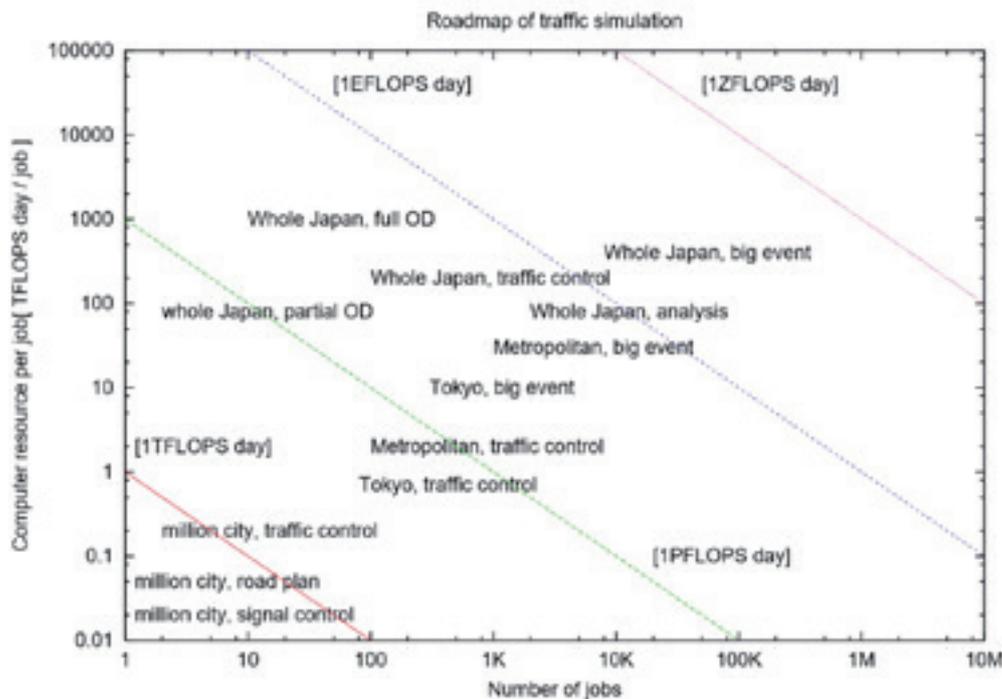


Figure 7.1: Roadmap of traffic simulations.

Another example is human relations. Some are friendly connected, and some are competing. Such human relations are known to be characterized by a small-world structure.

Figure 7.1, 7.2 and 7.3 show roadmaps of social simulations[1]. They show estimated computer resources estimated to be necessary to solve some social challenges. The horizontal axis shows typical number of simulations to solve a challenge, and the vertical axis shows resources for one simulation of the challenge. They are plotted with logarithmic scale and therefore lines $y = -x$ show total resources for the challenge.

These features are typically observed in simulations of particle, magnetic, biological and medical systems and also of social systems, for example, traffic, economy and social relationship. The Discrete-event simulation research team (DESRT) have been elucidating future applications of the K and future supercomputers to such social simulation. It is observed that computer applications to social issues will be more feasible when Peta-flops computer becomes popular. It is exactly the situation now we are. And this trend will be the more important when Exa- and Zeta-flops machines are available.

7.2.1 Parameter-space explorer: OACIS and CARAVAN

Discrete-event simulations usually require simulations for many parameters. We can design, submit and analyze a few to tens of parameters by hand, but it is hard for thousands or more, although millions of simulations are often necessary. Furthermore, next parameters are often determined based of simulation results with previous parameters. So a naive map-reduce type execution is not always useful. So we need some application tools to remedy the situation.

The DESRT has been developing job management tools named OACIS and CARAVAN to challenge the huge-parameter space. The name OACIS is an abbreviation of "Organizing Assistant for Comprehensive and Interactive Simulations"[2]. The OACIS and CARAVAN are not only to help crawling in parameter space, but also to connect various applications.

The OACIS have been released for public use as an AICS software, and the CARAVAN is now being tested with its prerelease version. Both of these two tools are used with user's simulation and analysis softwares. A user register one's simulation and analysis softwares together with their input parameters and available host computers to these tools, then the tools control submitting and analyzing jobs.

Each simulation and each analysis for many parameters will be properly processed by computers if they are specified correctly, but error will easily be introduced by human side. In this sense, supercomputers are de-

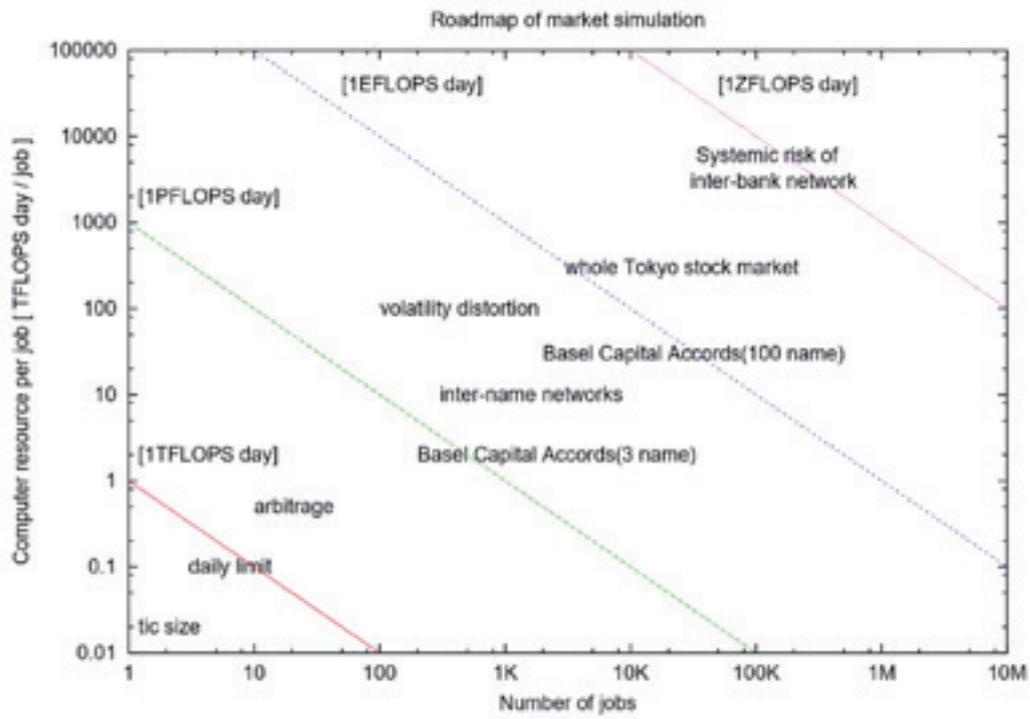


Figure 7.2: Roadmap of market simulations.

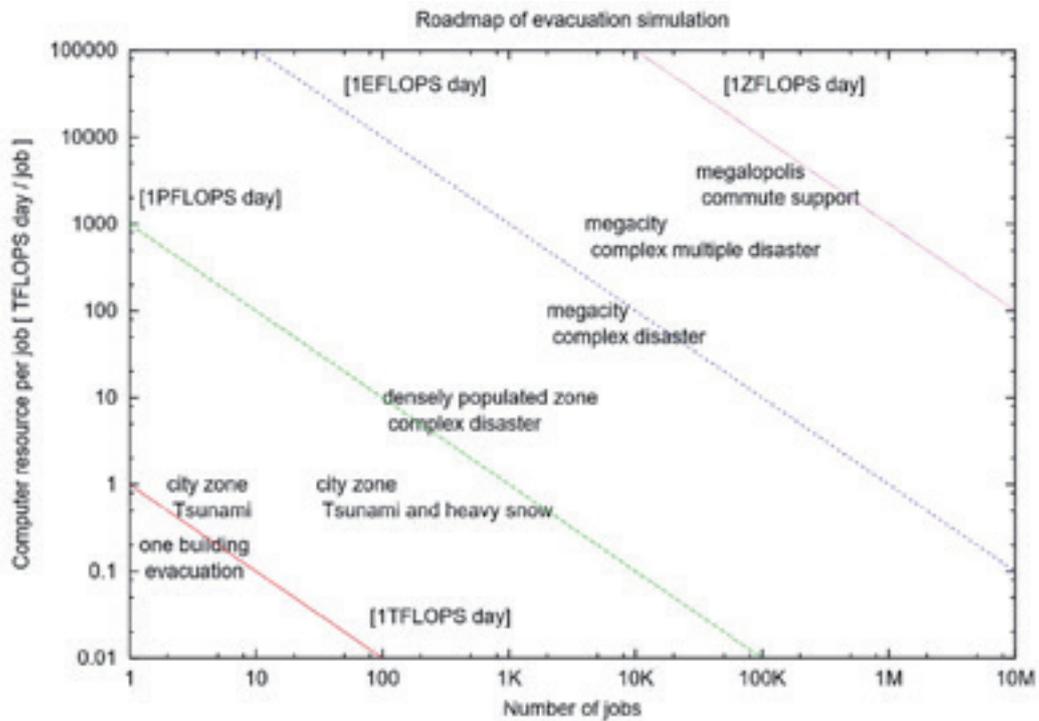


Figure 7.3: Roadmap of evacuation simulations.

manding not only greater programming skill but also more reliable operation and smarter decision of simulation parameters. The OACIS and CARAVAN are designed to solve this demand. A difference of the two tools is number of jobs and/or parameter sets. The OACIS is designed for jobs up to $10^6 \sim 10^7$ different parameters, and the CARAVAN to 10^9 and more.

The OACIS, a job management tool for simulations and analyses are designed and developed in DESRT. It is coded using Ruby, Ruby-on-rail framework and MongoDB. After installation, users register their applications for simulations and analyses, and their computers from PC to supercomputers like K to the OACIS. Then they can design and order executions of simulations and analyses on its web-browser front end. The ssh connection is used to operate the registered remote computers and Job states are supervised by the OACIS. Current prototype transfers output files of simulations and analysis to the local computer operating the OACIS from remote computers. The results and historical data are preserved in local computer using MongoDB.

Applications and users of the OACIS have been growing in and out of AICS. As an example, the OACIS is applied to the RoboCupRescue Simulation[3]. In the RoboCupRescue Simulation, many teams made up and delivered their agent application for a specified rescue task, and the OACIS is used to rate their efficiency.

In this year 2017, improvement debugging, and user support have been continued. The CARAVAN is coded with a PGAS language X10 implemented to the K computer. A preliminary version was released in this year.

7.2.2 Social modeling and simulations

The DESRT has a perspective to challenge the social complexity by combining three major components: traffic, economics and social relations, and we have been committed to develop those models and simulations with the K computer, collaborating with many research groups in Kobe University, Ritsumeikan University, the University of Tokyo, the National Advanced Institute of Industrial Science and Technology, and IBM Japan. This collaboration named "CASSIA" had been supported by JST, CREST. In this year 2017, we extended and updated this collaboration and started a new research project named "PostK-MultiSESIM" supported by MEXT as "Exploratory Challenges on Post-K computer(Studies of multi-level spatiotemporal simulation of socioeconomic phenomena)".

7.2.2.1 Traffic model: Macroscopic fundamental diagram

Car traffic are typical traffic mode, and its simulations have been applied to reduce jam, pollution and accidents. There are many car-traffic models, and they have a lot of degree of freedom and parameters. Road network and traffic rules are complicated, and set of origin and destination(OD set), is not well determined. Only for a single straight road, models and their behavior are established. But beyond this simple situation, reproduced traffic depends highly on a model used for simulations.

Traffic on a single straight road is characterized by a relation of car density ρ and car flux f , which is called as a "fundamental diagram(FD)". In low density, car flux is proportional to car density with a coefficient corresponding to a speed limit. In high density, flux decreases with density. Such unimodal $f(\rho)$ characterizes the traffic.

It has been proposed that a similar fundamental diagram may exist in traffic of urban network¹, and it is called as a "macroscopic fundamental diagram(MFD)". So we have studied a density-flux relation on a simple road network with models and simulations[4]. The road network we studied is N roads from a crossing coming back to the same crossing(left in Fig. 7.1). All of N roads have the same length, L . For this simplest road networks, two kinds of traffic models are analysed. One is to replace each road with a nonlinear register obeying a FD, that is,

$$f(\rho_i) = \begin{cases} v\rho_i & \text{if } \rho_i \leq \rho_P \\ w(1 - \rho_i) & \text{if } \rho_P \leq \rho_i < 1 \end{cases} \quad (7.1)$$

where ρ_i denotes car density of a road $i(i = 1, 2, \dots, N)$ with speed limit v , $\rho_P \equiv 1/v$ and $w \equiv (1 - 1/v)^{-1}$. And density ρ_i develops obeying a evolution equation,

$$\frac{d\rho_i}{dt} = \frac{1}{N-n} \sum_{j=1}^N f(\rho_j) - f(\rho_i), \quad n = \sum_{i=1}^N \delta_{f(\rho_i),1}, \quad (7.2)$$

¹N. Geroliminis and C. F. Daganzo, Transp. Res. B vol.42, p.759 (2008)

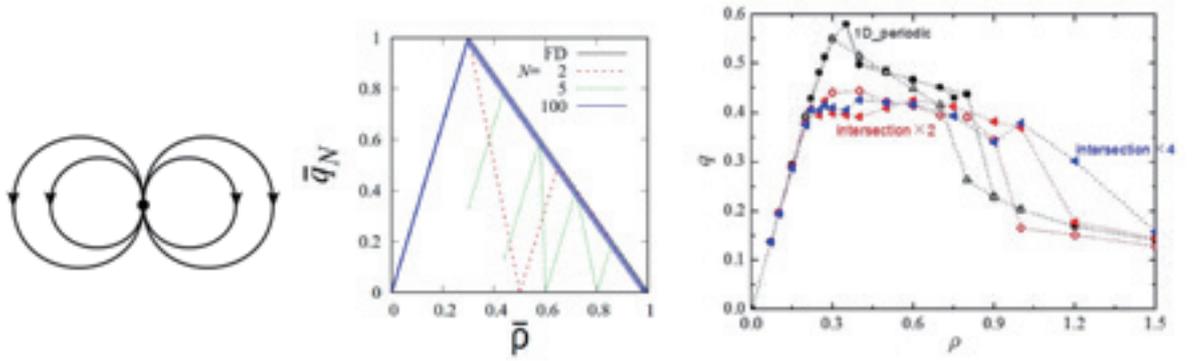


Table 7.1: A road network with $N = 4$ is shown (left). MFD of a nonlinear register model (middle) and of a OV model (right) is plotted.

where n denotes number of roads with density 1, that is, fully occupied. The other is to use car agents obeying an optimal-velocity model, that is, position x of a car obeys an equation,

$$\frac{d^2x}{dt^2} = a[V(\Delta) - \frac{dx}{dt}], \quad V(\Delta) = \tanh(\Delta - 2) + \tanh 2, \quad (7.3)$$

where Δ denotes distance from a car in front and a is a constant. Each car randomly selects one of the N roads at everytime when they are approaching to the crossing.

MFD of a model which represent each road as a nonlinear register obeying a FD is in middle of Fig. 7.1), and another MFD of another model and simulation with agent cars obeying a OV model is in right of Fig. 7.1). The result of nonlinear register model, a continuum model of traffic, does not show unimodal but many branches depending of the number of roads, N . But an OV agent model shows unimodal MFD, and this agent model explains an origin of the observed MFD. Furthermore, a continuum flow model of traffic does not reproduce MFD of network traffic.

7.2.2.2 Evacuation planning

Evacuation planning is important to minimize damage from disasters and accidents. In the past year, we had studied evacuation simulation from Tsunami attack in coastal area of Kanazawa and Kamakura cities, assuming different scenarios and parameters up to four million. In this year 2017, we have challenged to select optimal evacuation plan from computer simulations and genetic optimization.

Finding an evacuation plan finishing in shortest time sounds to be the best but it tends to be complicated. Complicated plans will not be realized because most evacuees can not completely follow a lengthy order. There is a trade-off relation between complexity of plan(S) and evacuation time(T). So an optimal plan is one that no other plan has smaller S and T. Such plan will show a curve in S-T plane, and it is a Paletto optimal curve. Computer simulations are applied to find the curve for Nishiyodogawa ward in coastal low area of Osaka city using a evacuation model.

Nishiyodogawa ward has 73 areas and 86 safe evacuation places from Tsunami attack. Its road map has 2933 nodes and 8924 links. We assumed that there are 49276 evacuees distributed in the map. Evacuees in each of 73 areas are divided into two groups with population ratio $x:(1-x)$, and each group is planned to go to one specified safe place via one of 533 check-points, which is big corner, landmark and others.

An evacuation plan consists of a list of population fraction $x_i (i = 1, 2, \dots, 73)$ and $146 = 73 * 2$ check-points and 146 safe places Plan complexity S is measured with distribution entropy, $S = \sum_i x_i \log x_i$. This list is coded in a genetic sequence, and an evacuation simulation obeying one plan in a genetic sequence is executed and evacuation time is estimated. Starting from a random group of genetic sequences, their evacuation times, T are plotted versus their complexity, S (Fig. 7.4). Using a genetic optimization algorithm is applied to get a Paletto optimal evacuation plans. After hundreds generations, obtained Paletto plans converges to a curve (Fig. 7.5).

It is observed in the result in Fig. 7.5 that a evacuation time does not improve much for complex plan. From simplest plan, evacuation time reduces much adding a bit complexity to plan. Therefore we can conclude that one plan in left-bottom of the curve will be a good candidate for evacuation plan.

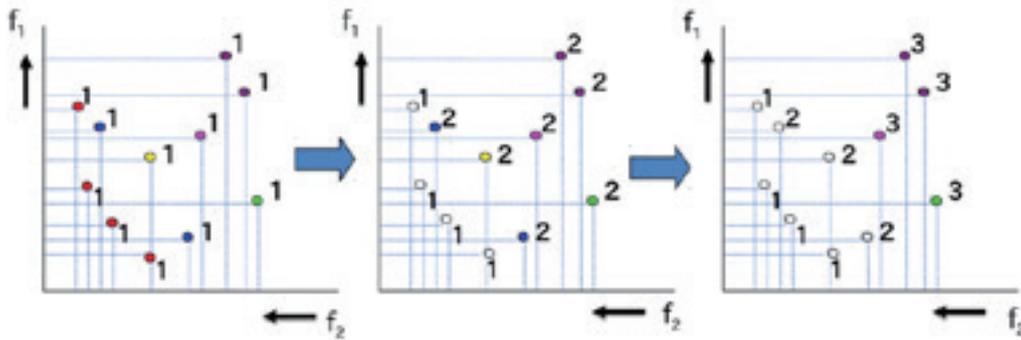


Figure 7.4: A group of genetic sequences of evacuation plans are simulated and their evacuation time is plotted versus their complexity. Sequences of Pareto optimal plan are selected for the next generation, and they are mutated and crossed over for the next generation of genetic pool. This procedure is repeated hundreds generations.

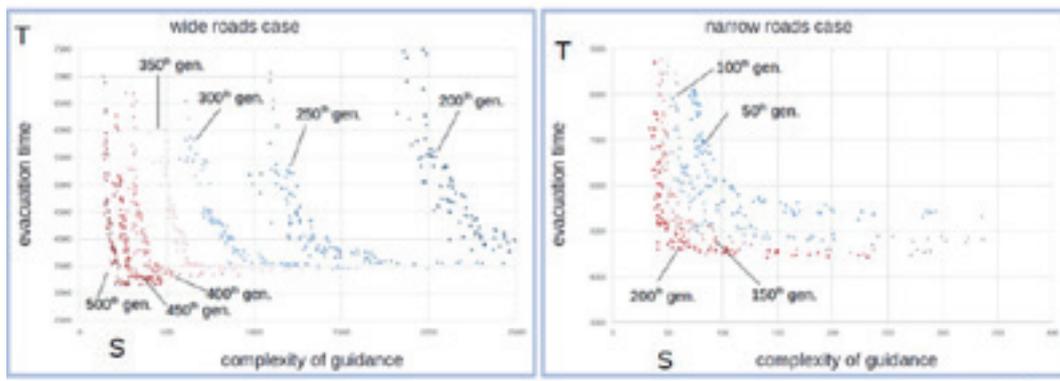


Figure 7.5: Pareto plans converges to a curve after hundreds generation. Left is for a case using only pedestrian area for evacuation, and right using all area of road.

This study was executed using the OACIS, and it will be an example that computer simulations help to make socio-political decision.

7.2.3 Other activities

In the year of 2017, following studies were published from this team:

- [1] Model development of human relationship[5]
- [2] Simulation study of pack-flock dynamics[6]
- [3] Simulation study of particle incident on granular bed[7]

7.3 Schedule and Future Plan

From the research activities of DESRT so far, following problems are becoming clear:

- [1] Simulation models, typically social ones, comprise with large input parameters and output numbers, and their behaviors are strongly nonlinear with various regimes.
- [2] Social “big data” are often not big enough to picture details. It is clearly observed from our multivariate analysis of the traffic data. Thousands of samples are necessary to get minor traffic factors, but such

repetitions are not expected in the real traffic. Weather, economics, calendar, accidents and other factors varies every day.

- [3] Development of multiscale social and economic models and simulations.

7.4 Publications

7.4.1 Articles

- [1] Itsuki Noda, Nobuyasu Ito, Kiyoshi Izumi, Hideki Mizuta, Tomio Kamada and Hiromitsu Hattori, “Roadmap and research issues of multiagent social simulation using high-performance computing”, *J. Comput. Soc. Sci.* (2018) vol.1 p.155-166.
- [2] Y. Murase, T. Uchitane and N. Ito, “An open-source job management framework for parameter-space exploration: OACIS”, *J. Phys.: Conf. Ser.* vol. 921 (2017) 012001.
- [3] Shunki Takami, Kazuo Takayanagi, Shivashish Jaishy, Nobuhiro Ito, Kazunori Iwata, Yohsuke Murase, and Takeshi Uchitane “Proposed environment to support development and experiment in RoboCupRescue Simulation” to appear in *RoboCup 2017: Robot World Cup XXI*.
- [4] 寺田健司、吉岡直樹、島田尚、伊藤伸泰、「単純な道路ネットワークにおける都市交通の巨視的基本図」、第23回交通流と自己駆動粒子系のシンポジウム論文集、5a-2 (2017).
- [5] Janos Kertesz, Janos Torok, Yohsuke Murase, Hang-Hyun Jo, Kimmo Kaski ”Multiplex Modeling of the Society” to appear in the Springer volume on Multiplex Network, within H2020 Multiplex Project
- [6] Makoto Masuko, Takayuki Hiraoka, Nobuyasu Ito, Takashi Shimada, “The effect of laziness in group chase and escape”, *J. Phys. Soc. Jpn.* vol.86 (2017) 085002.
- [7] Takahiro Tanabe, Takashi Shimada, Nobuyasu Ito and Hiraku Nishimori, “Splash detail due to a single grain incident on a granular bed”, *Physical Review E* vol.95 (2017) 022906.

7.4.2 Invited Talks

- [7] Nobuyasu Ito, “Social simulation on HPC”, IX Brazilian Meeting on Simulational Physics (BMSP) (Natal, Brazil, August 21-25, 2017).
- [8] Nobuyasu Ito, “Car traffic modelings and simulations”, The 4th International Workshop on Physics of Social Complexity (May. 27, 2017, Sobaeksan Optical Astronomy Observatory, Danyang, Republic of Korea).
- [9] 伊藤伸泰「自動車交通シミュレーションとその応用」(「計算社会科学の可能性」講演(5)), 情報処理学会第80回全国大会(2018年3月13-15日、早稲田大学西早稲田キャンパス)
- [10] 伊藤伸泰「次世代スパコンと社会シミュレーション」, 経済・社会への分野横断的研究会(キヤノングローバル戦略研究所・東京、2017年9月25-26日)
- [11] 伊藤伸泰「社会シミュレーションとスーパーコンピュータ」, 第19回KECテクノフォーラム(2018年1月23日グランフロント大阪)
- [12] Yohsuke Murase, Takashi Shimada, and Per Arne Rikvold”Effects of demographic stochasticity on biological community assembly on evolutionary time scales”, The 4th International Workshop on Physics of Social Complexity (PoSCo), Danyang, Republic of Korea, 26th - 28th May, 2017
- [13] 村瀬洋介「網羅的シミュレーション実行フレームワーク」ポスト「京」萌芽的課題「基礎科学の挑戦」サブ課題B「相転移と流動」公開シンポジウム

7.4.3 Oral Talks

- [14] Nobuyasu Ito, “Car traffic simulation of Kobe city”, The Japan-Hungary bilateral workshop (March 22, 2018, Fukui, Japan).
- [15] Nobuyasu Ito, “Order-disorder transition in repulsive self-propelled particle systems”, 8th Hungary-Japan Bilateral Workshop on Statistical Physics of Breakdown Phenomena (Nov. 23 2017, Debrecen, Hungary).
- [16] Nobuyasu Ito, “Social simulation and HPC”, The 2nd Workshop on Self-Organization and Robustness of Evolving Many-Body Systems (September 8-9, 2017, Sapporo, Japan).
- [17] 吉岡直樹・稲岡創・伊藤伸泰・Fengping Jin・Kristel Michielsen・Hans De Raedt「京による量子コンピュータのシミュレーション」(23aA19-8), 日本物理学会2017年秋季大会(岩手大学上田キャンパス、2017年9月21-24日)
- [18] 増子真・平岡喬之・伊藤伸泰・島田尚「集団追跡における怠けの効用」, 日本物理学会2017年秋季大会(岩手大学上田キャンパス、2017年9月21-24日)

- [19] 広谷渉・島田尚・伊藤伸泰「青空文庫における名詞バイグラムの解析」, 日本物理学会 2017 年秋季大会 (岩手大学上田キャンパス, 2017 年 9 月 21-24 日)
- [20] 榎本大悟・土屋晴文・中澤知洋・湯浅孝之・榎戸輝揚・牧島一夫・古田禄大・玉川徹・伊藤伸泰「GROWTH 実験 2014 年度データを用いた雷雲ガンマ線のイベント探索法の改善」, 日本物理学会 2017 年秋季大会 (宇都宮大学峰キャンパス, 2017 年 9 月 12-15 日)
- [21] 村瀬洋介「社会ネットワークにおけるサンプリングバイアス」, ネットワーク科学セミナー 2017
- [22] Yohsuke Murase, Seung Ki Baek "Finding Nash equilibria for the public-goods game using a supercomputer" The 2nd Workshop on Self-Organization and Robustness of Evolving Many-Body Systems
- [23] Naoki Yoshioka, Hajime Inaoka, Nobuyasu Ito, Fengping Jin, Kristel Michielsen, Hans De Raedt, Simulations of quantum computers on supercomputers, 30th Annual Workshop on Recent Developments in Computer Simulation Studies in Condensed Matter Physics, (Georgia University, Athens, USA, Feb. 26-28, 2017).
- [24] 島田尚, 吉岡直樹, 「粉体層中を準静的に動く球体間に働く相互作用」, 日本物理学会第 72 回年次大会 (大阪大学, 大阪, 3 月 17-20 日, 2017).
- [25] 吉岡直樹, 稲岡創, 伊藤伸泰, Fengping Jin, Kristel Michielsen, Hans De Raedt, 「量子コンピュータの大規模並列シミュレーション」, 日本物理学会第 72 回年次大会 (大阪大学, 大阪, 3 月 17-20 日, 2017).
- [26] Naoki Yoshioka, Ferenc Kun, and Nobuyasu Ito, Kinetic Monte Carlo algorithm for thermally induced breakdown of fiber bundles, The 4th International Workshop on Physics of Social Complexity (PoSCo) (Sobaeksan, Korea, May 26-28, 2017).
- [27] Naoki Yoshioka, Takashi Shimada, and Nobuyasu Ito, Stability and macroscopic fundamental diagram in simple model of urban traffic, The 2nd Workshop on Self-Organization and Robustness of Evolving Many-Body Systems (Hokkaido University, Sapporo, Japan, Sep. 8-9, 2017).
- [28] Naoki Yoshioka, Ferenc Kun, and Nobuyasu Ito, Jump distance of epicenters in thermally induced cracking, 8th Hungary-Japan Bilateral Workshop on Statistical Physics of Breakdown Phenomena (Debrecen, Hungary, Nov. 22-23, 2017).
- [29] 寺田健司, 吉岡直樹, 島田尚, 伊藤伸泰, 「単純な道路ネットワークにおける都市交通の巨視的基本図」, 第 23 回交通流と自己駆動粒子系のシンポジウム (名古屋大学, 名古屋, 12 月 4-5 日, 2017).

7.4.4 Software

- [30] OACIS and CARAVAN