網羅的アプローチによる
社会シミュレーション

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今日の内容

- 社会シミュレーションとは？
- 網羅的探索のためのフレームワーク
- ゲーム理論の研究紹介
    - 「京」が考えた公共財ゲームの最強戦略

社会シミュレーションとは？

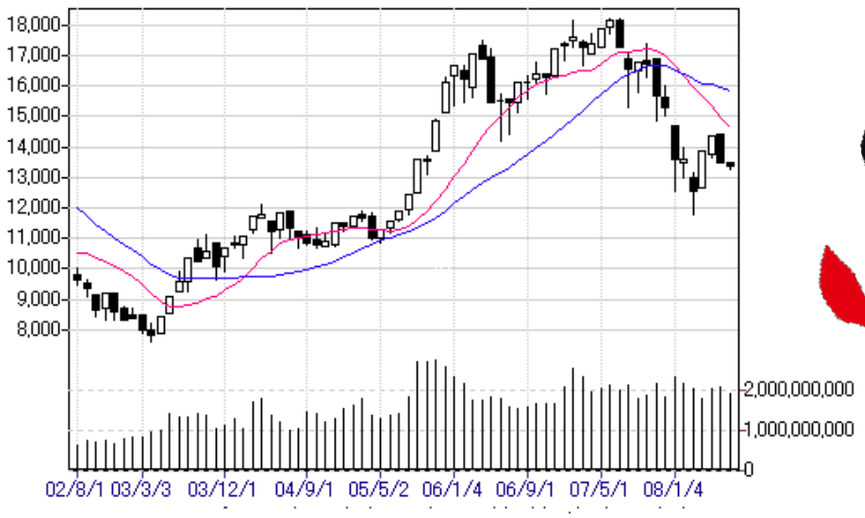
社会現象を対象としたシミュレーション

具体的には？

交通

By Koika - 投稿者自身による作品, CC 表示-継承 1.0, https://commons.wikimedia.org/w/index.php?curid=4818322

経済



By 久保愛美 - 久保愛美, パブリック・ドメイン, https://commons.wikimedia.org/w/index.php?curid=36898977

社会ネットワーク

科学における３ステップ

観測

Analysis

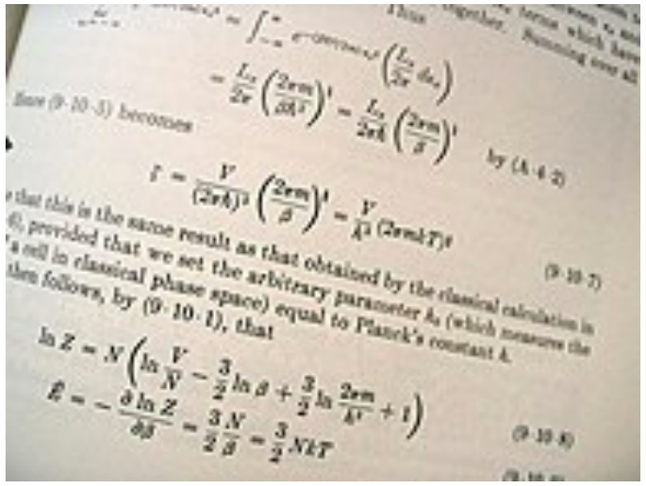
モデル化・理解

Modeling

予測・制御

Prediction

By Halfblue, CC 表示-継承 3.0, https://commons.wikimedia.org/w/index.php?curid=1137463



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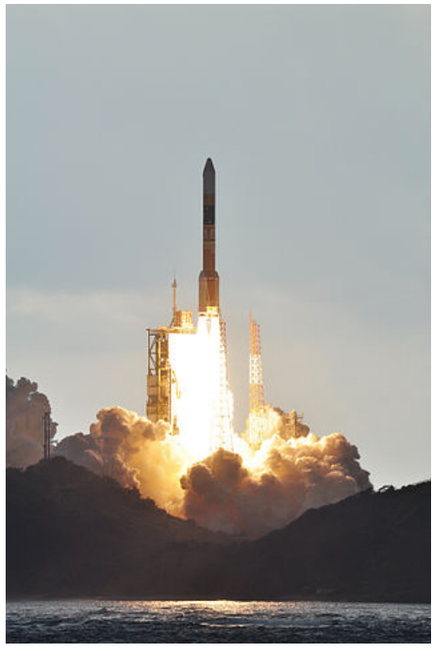

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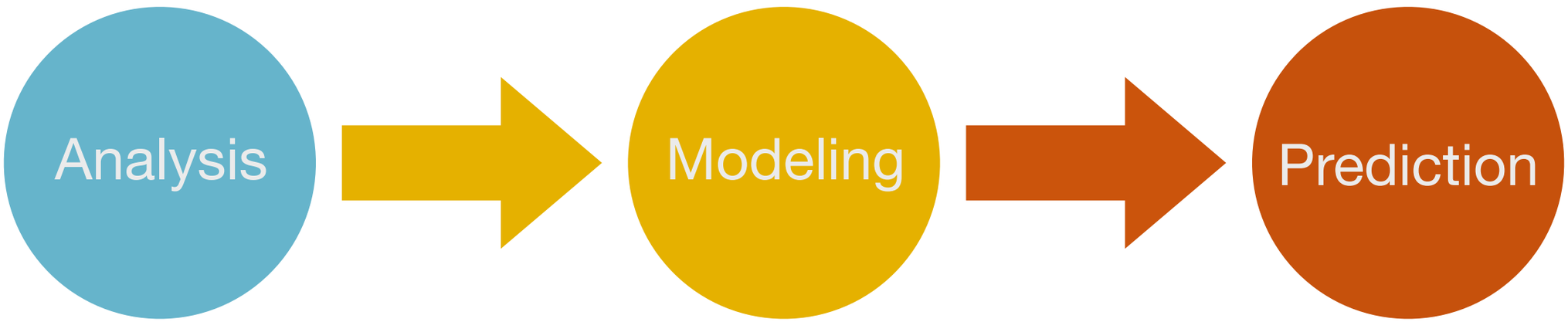
観測

モデル化・理解

予測・制御



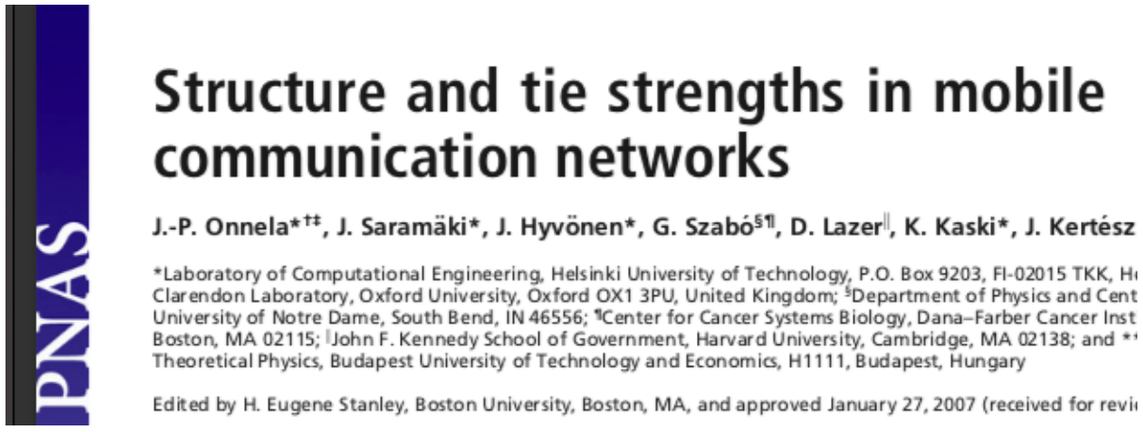
Big Data
Internet of Things

統計モデル
マルチエージェントモデル

機械学習
シミュレーション

Big-data & 機械学習

- Big Dataによるブレークスルー
  - 機械学習により非定型データも解析できるようになった
  - Computational Social Science という分野の出現



PNAS

Structure and tie strengths in mobile communication networks

J.-P. Onnela*†‡, J. Saramäki*, J. Hyvönen*, G. Szabó§¶, D. Lazer‖, K. Kaski*, J. Kertész

*Laboratory of Computational Engineering, Helsinki University of Technology, P.O. Box 9203, FI-02015 TKK, H
Clarendon Laboratory, Oxford University, Oxford OX1 3PU, United Kingdom; §Department of Physics and Cent
University of Notre Dame, South Bend, IN 46556; ¶Center for Cancer Systems Biology, Dana–Farber Cancer Inst
Boston, MA 02115; ‖John F. Kennedy School of Government, Harvard University, Cambridge, MA 02138; and **
Theoretical Physics, Budapest University of Technology and Economics, H1111, Budapest, Hungary

Edited by H. Eugene Stanley, Boston University, Boston, MA, and approved January 27, 2007 (received for revi

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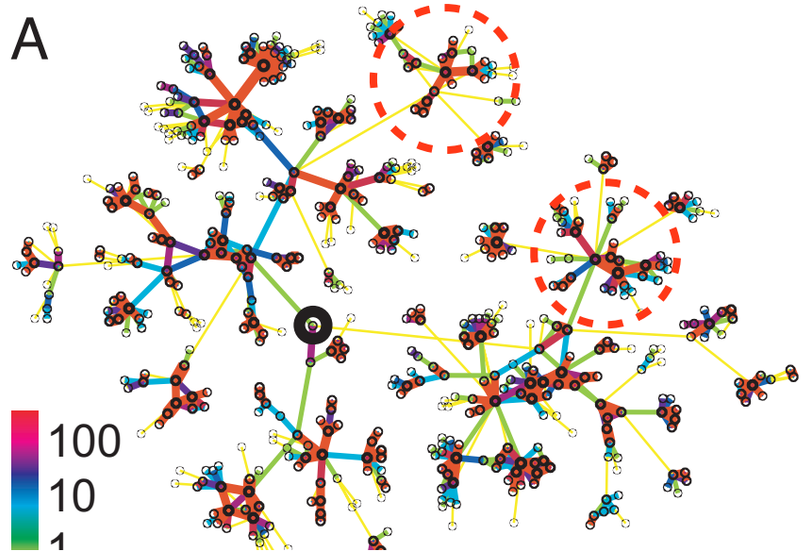
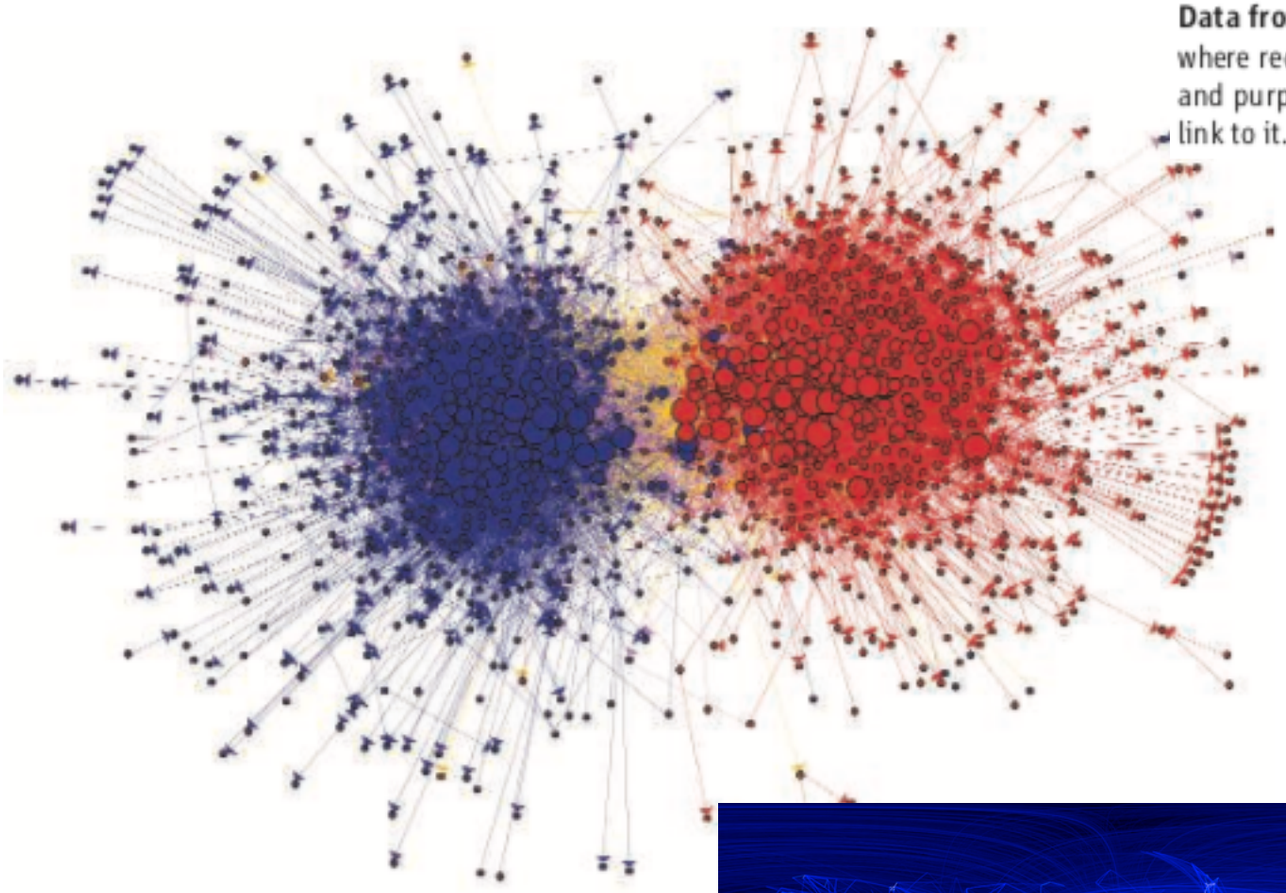


SOCIAL SCIENCE

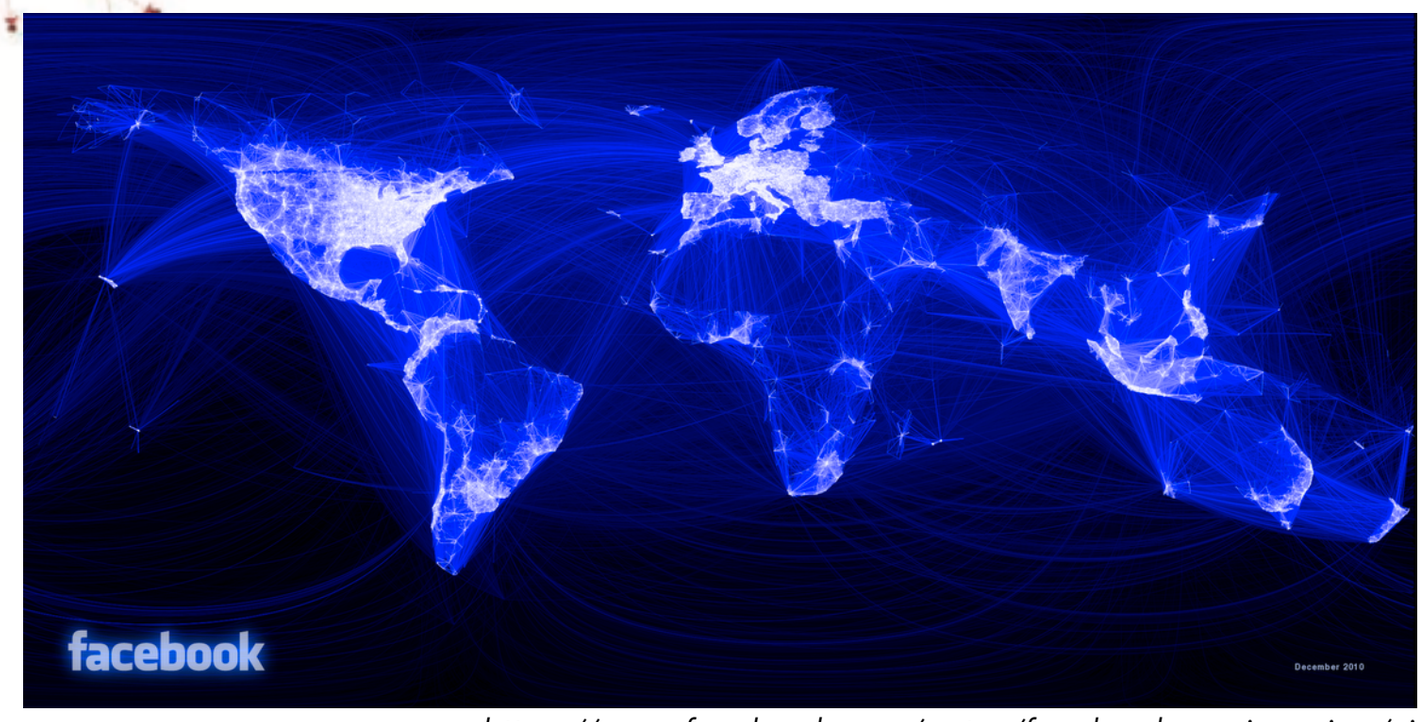
Computational Social Science

David Lazer,[1] Alex Pentland,[2] Lada Adamic,[3] Sinan Aral,[2,4] Albert-László Barabási,[5]
Devon Brewer,[6] Nicholas Christakis,[1] Noshir Contractor,[7] James Fowler,[8] Myron Gutmann,[3]
Tony Jebara,[9] Gary King,[1] Michael Macy,[10] Deb Roy,[2] Marshall Van Alstyne[2,11]

A field is emerging that leverages the capacity to collect and analyze data at a scale that may reveal patterns of individual and group behaviors.

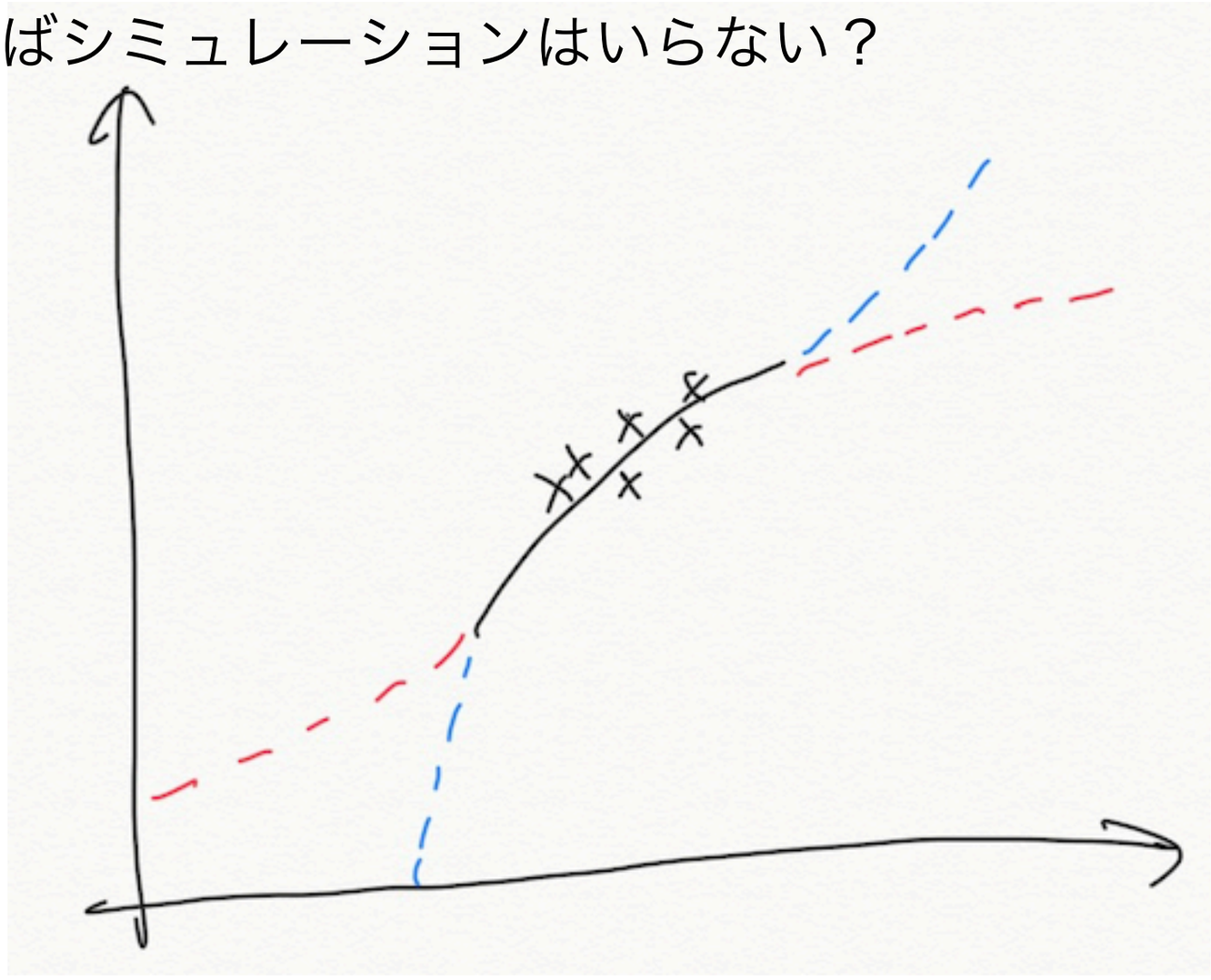


Data from the blogosphere. Shown is a link structure within a community of political blogs (from 2004), where red nodes indicate conservative blogs, and blue liberal. Orange links go from liberal to conservative, and purple ones from conservative to liberal. The size of each blog reflects the number of other blogs that link to it. [Reproduced from (*8*) with permission from the Association for Computing Machinery]



https://www.facebook.com/notes/facebook-engineering/visualizing-friendships/

機械学習さえあればシミュレーションはいらない？



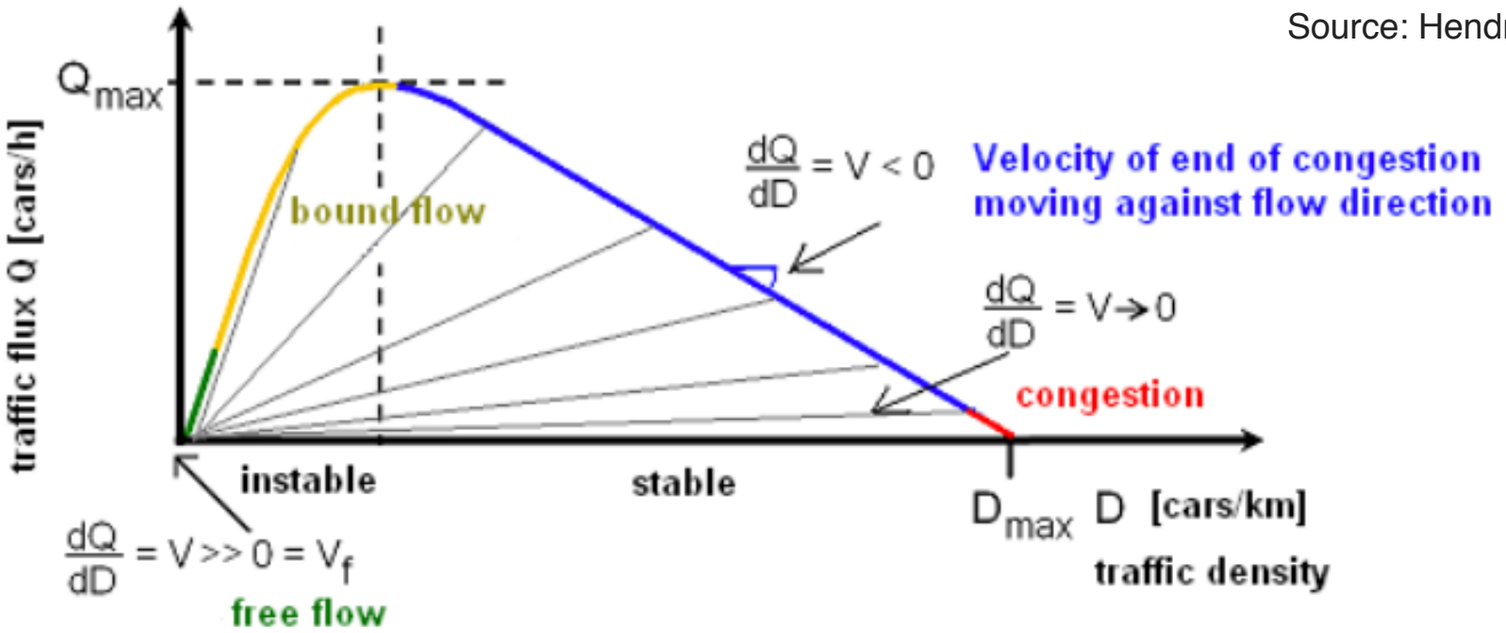
「データが得られる状況 ~= 予測したい状況」→ 予測しやすい

条件が大きく異なる場合 → データからだけでは決して予測できない

(例 : 災害時の状況、感染症の流行、政策を実行した場合の変化の予測)

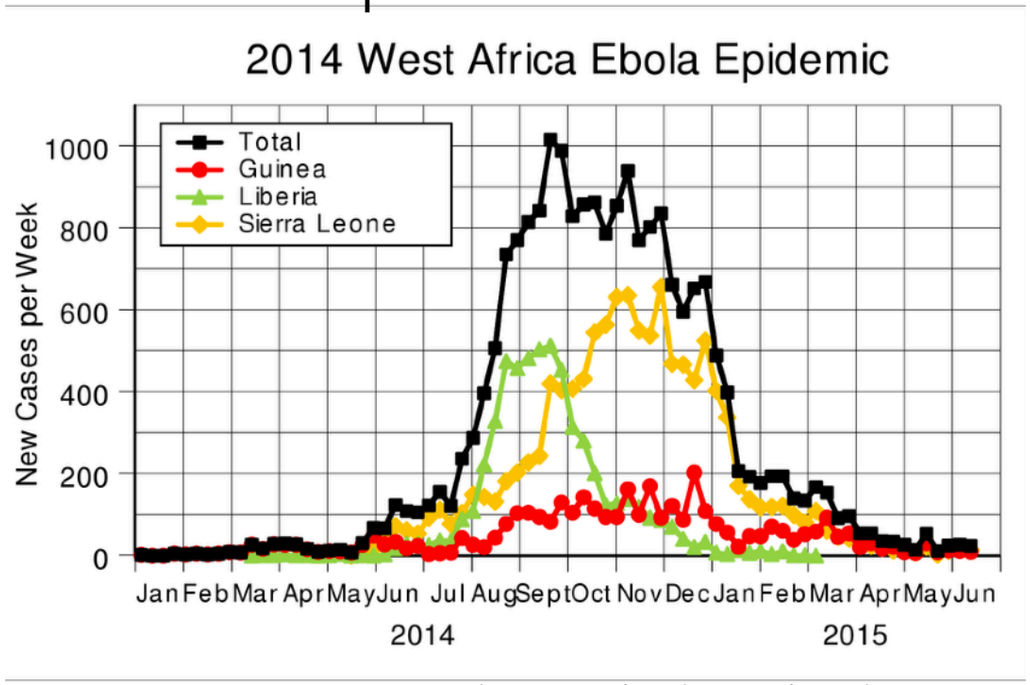
強い非線形性

traffic congestion



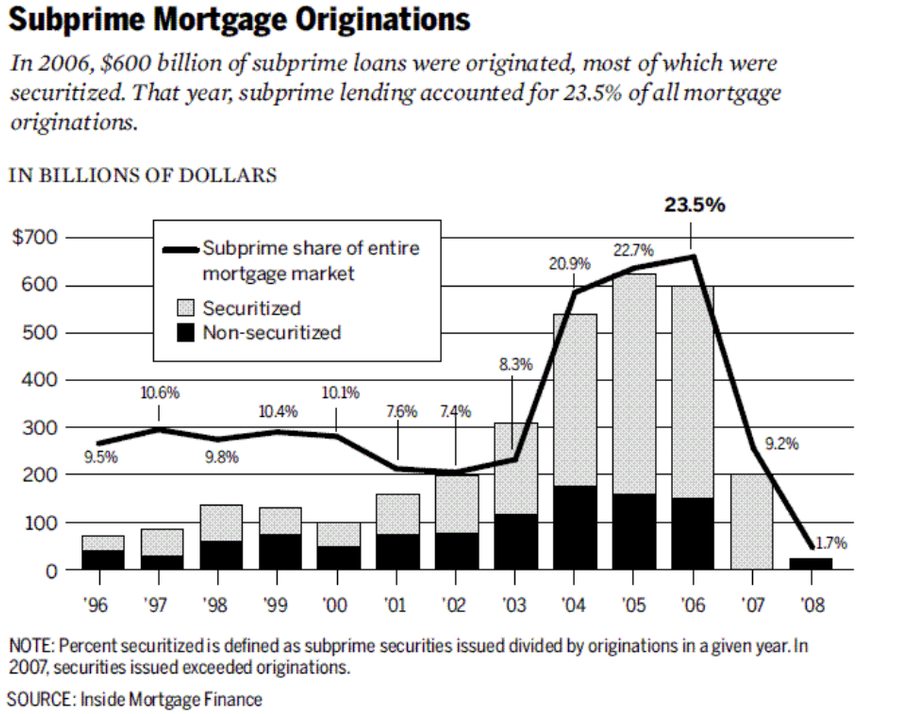
Fundamental diagram of traffic flow
Source: Hendrik Ammoser translated from german WP / CC BY SA 3.0

outbreak of epidemics



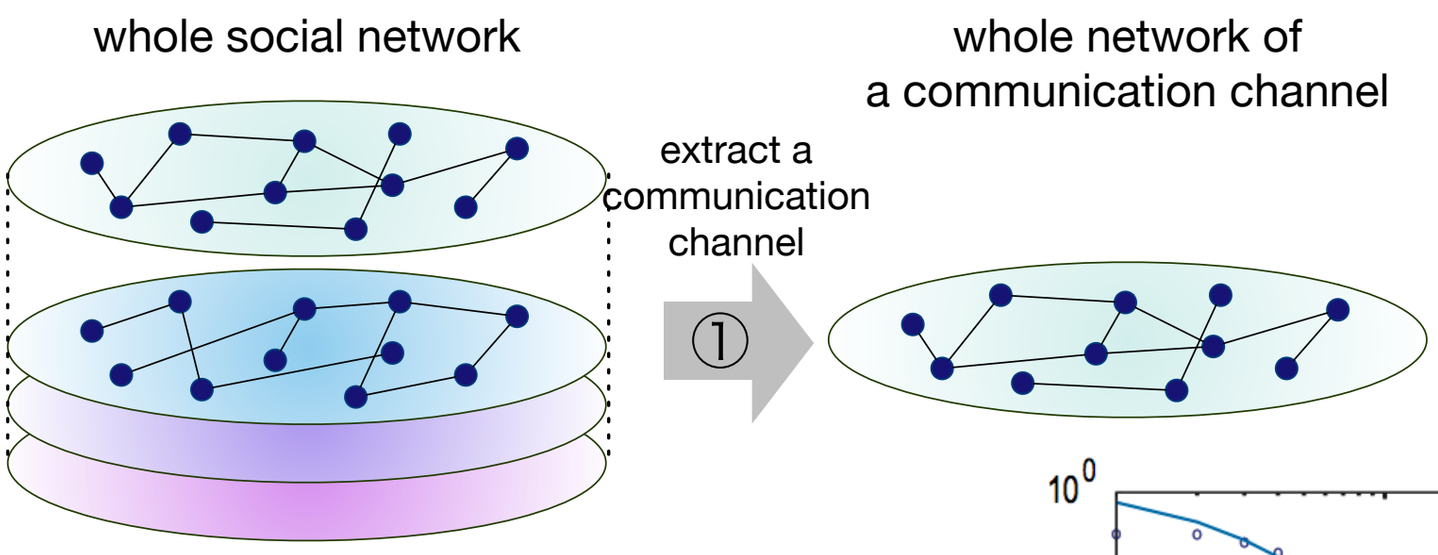
https://en.wikipedia.org/wiki/Epidemic

economic crisis

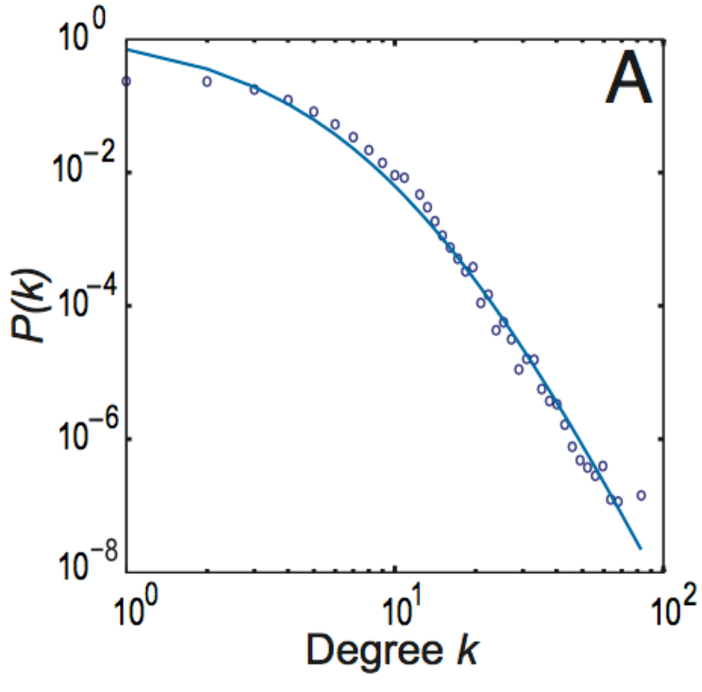


サンプリングバイアスの問題

我々が入手できるデータは、社会活動の一部を反映したもの
　技術上の問題、プライバシーの問題

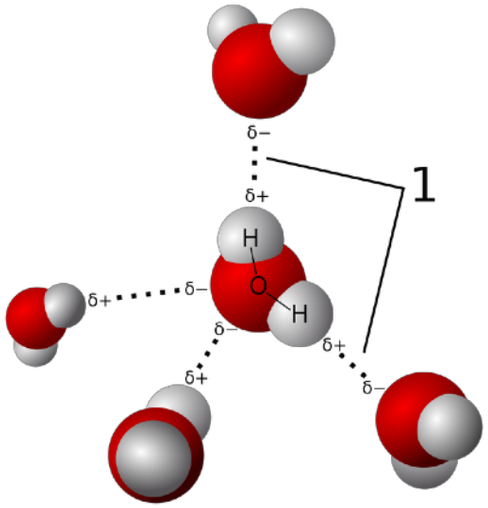


データは単調現象な分布。しかし、現実には友人が一人しかいない人はまずいない



強い非線形性の起源

微視的な相互作用



By User Qwerter at Czech wikipedia: Qwerter. Transferred from cs.wikipedia to Commons by sevela.p. Translated to english by by Michal Maňas (User:snek01). Vectorized by Magasjukur2 - File: 3D model hydrogen bonds in water.jpg, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=14929959

巨視的な性質

By José Manuel Suárez, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=4602887
By Wilson Bentley - Plate XIX of "Studies among the Snow Crystals ... " by Wilson Bentley, "The Snowflake Man." From Annual Summary of the "Monthly Weather Review" for 1902., Public Domain, https://commons.wikimedia.org/w/index.php?curid=22130
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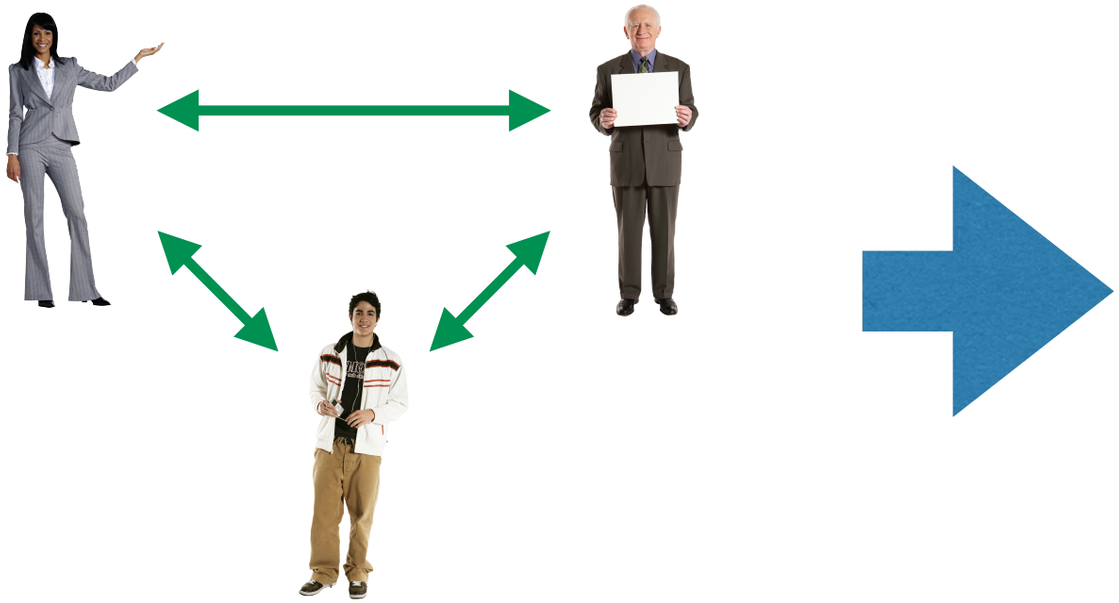
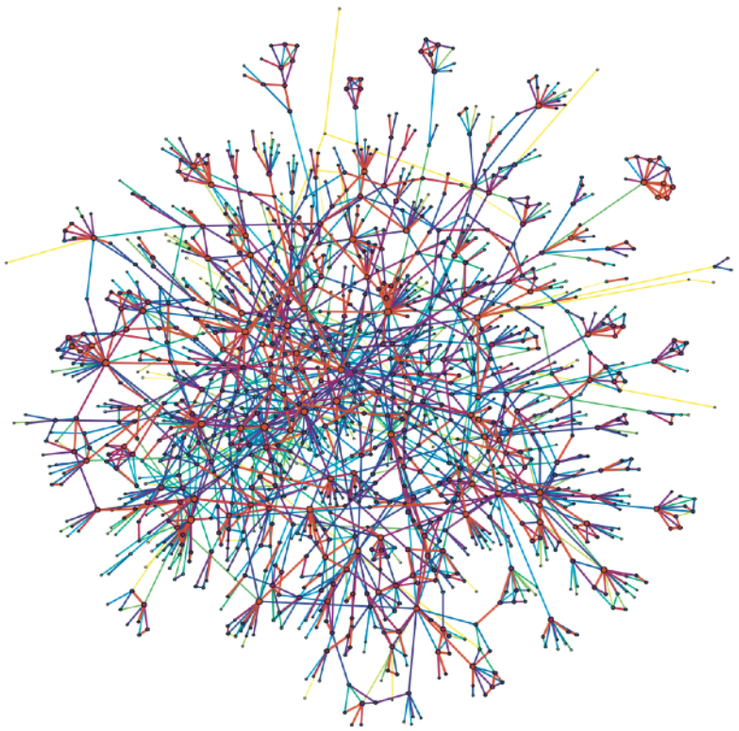
微視的な相互作用



巨視的な性質



人間ひとりひとりの活動 → 非自明な大域的な結果につながる

相転移、分岐、創発現象

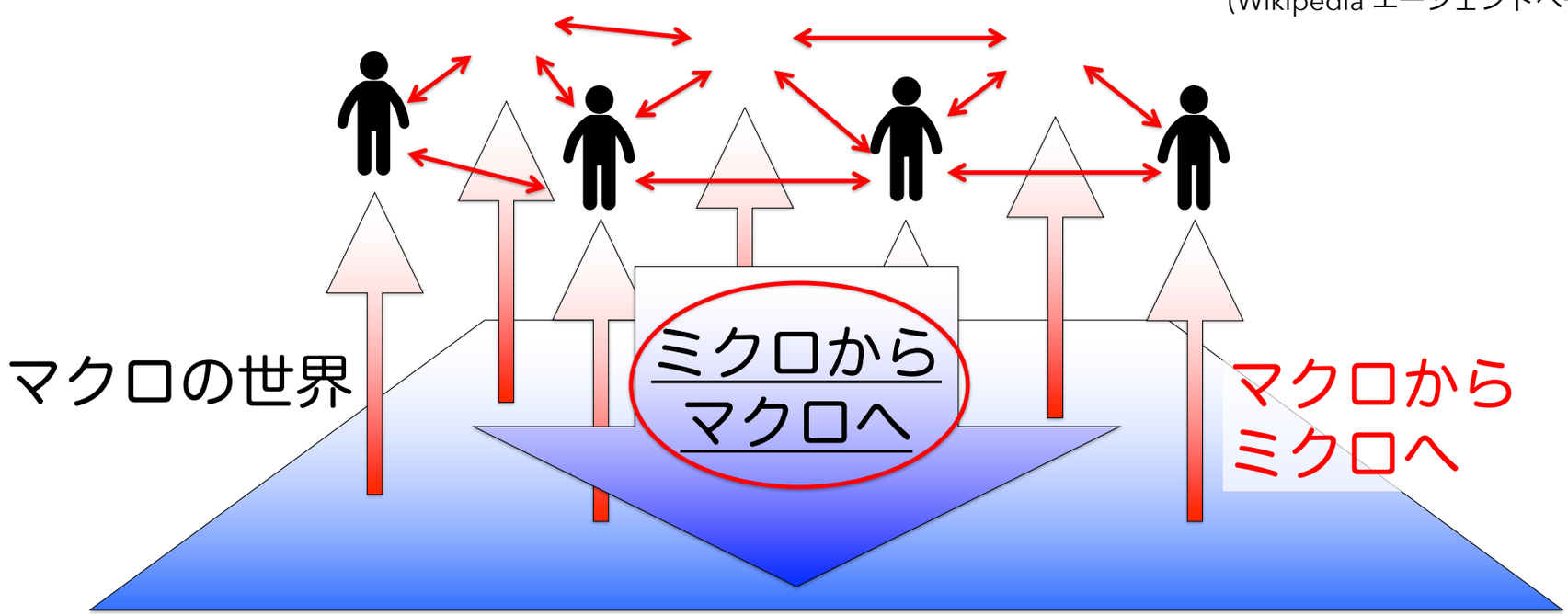
https://www.reddit.com/r/funny/comments/43wirn/just_a_normal_day_at_the_nations_most_important/

微視的な要素に基づいたモデル

Agent-Based Model

ABMは、複数のエージェントが同時に活動し、相互作用する状況をシミュレートすることによって、複雑な現象を再現し、予測することを目指す。ここで扱うプロセスは、システムの下位レベル（ミクロ）から上位レベル（マクロ）への創発現象の1つである。

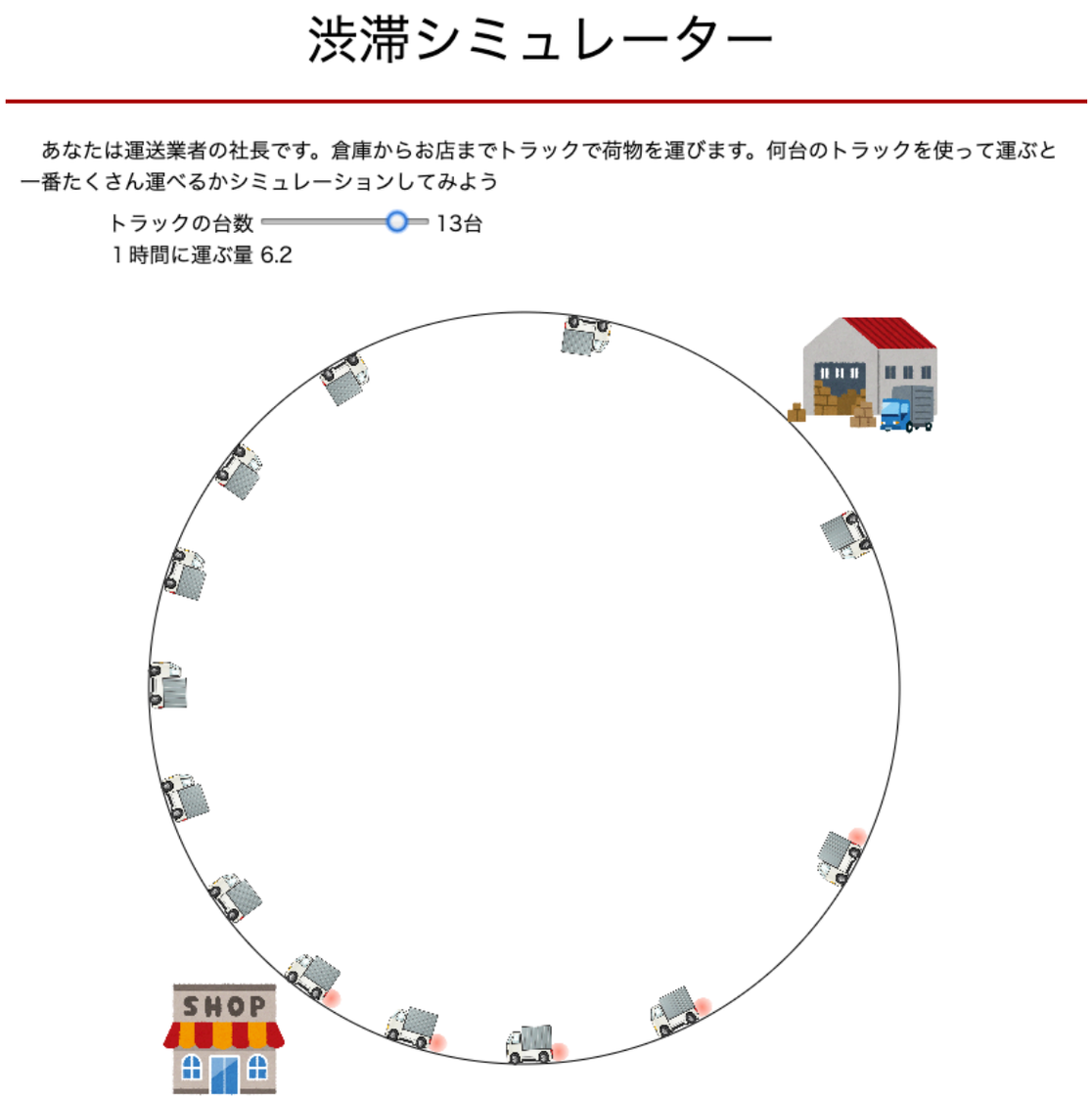
(Wikipedia エージェントベースモデルより)



抽象度の高いシンプルなモデルから、意思決定を目的とした工学的なものまで

簡単なABMの例

http://yohm.github.io/p5js_simulations/ov_model/

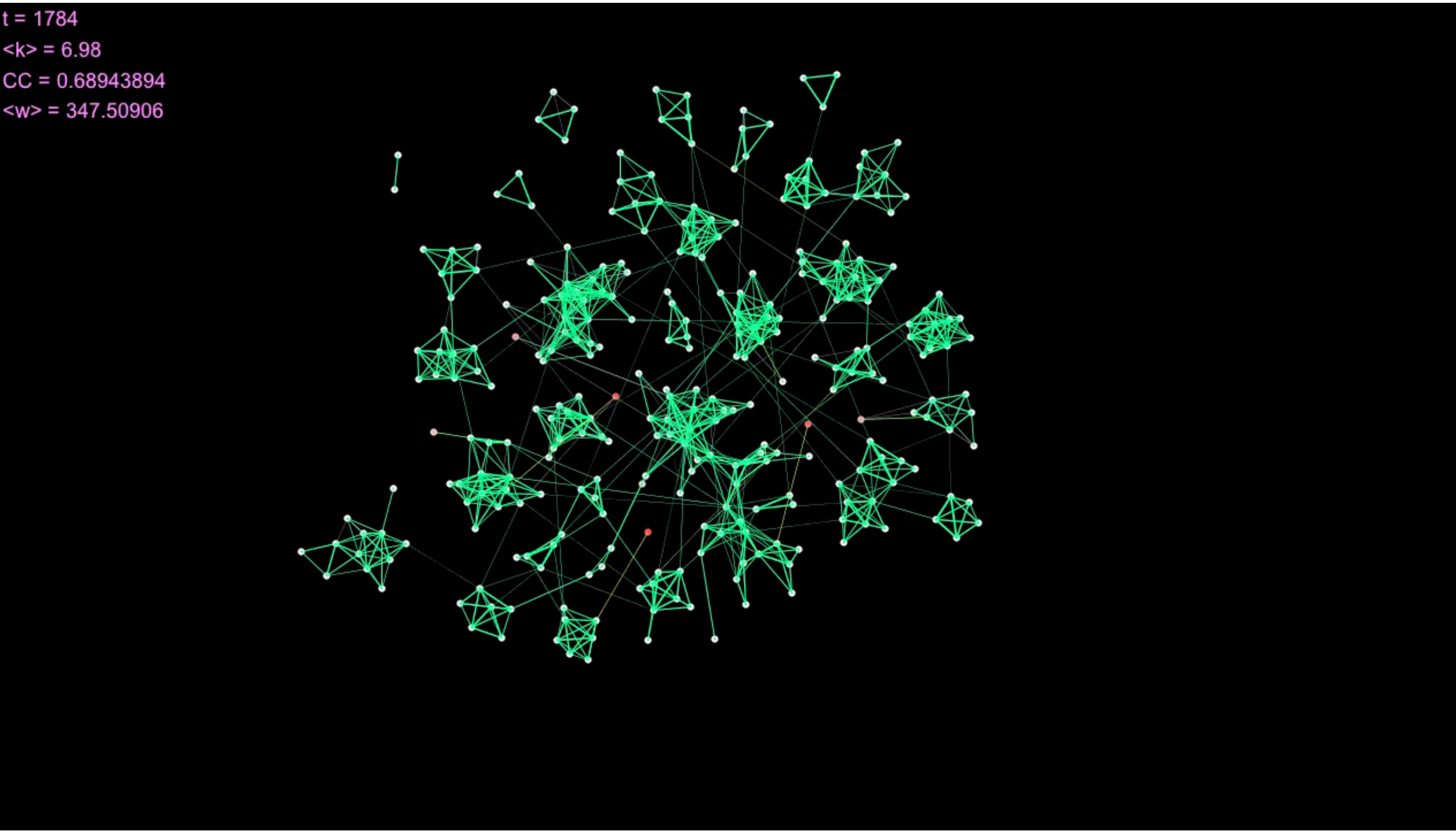


- ドライバーは前しか見ない(非対称性)
- ドライバーの判断に遅れが伴う(反応遅延)

参考 : 渋滞を再現する数理モデル https://qiita.com/kaityo256/items/36c2ba0ee63cb0c57fa3

社会ネットワーク

http://yohm.github.io/p5js_simulations/wsn/



より実用的・工学的な例

AIST
NATIONAL INSTITUTE OF
ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)

提供：野田グループ

交通計画の事前評価

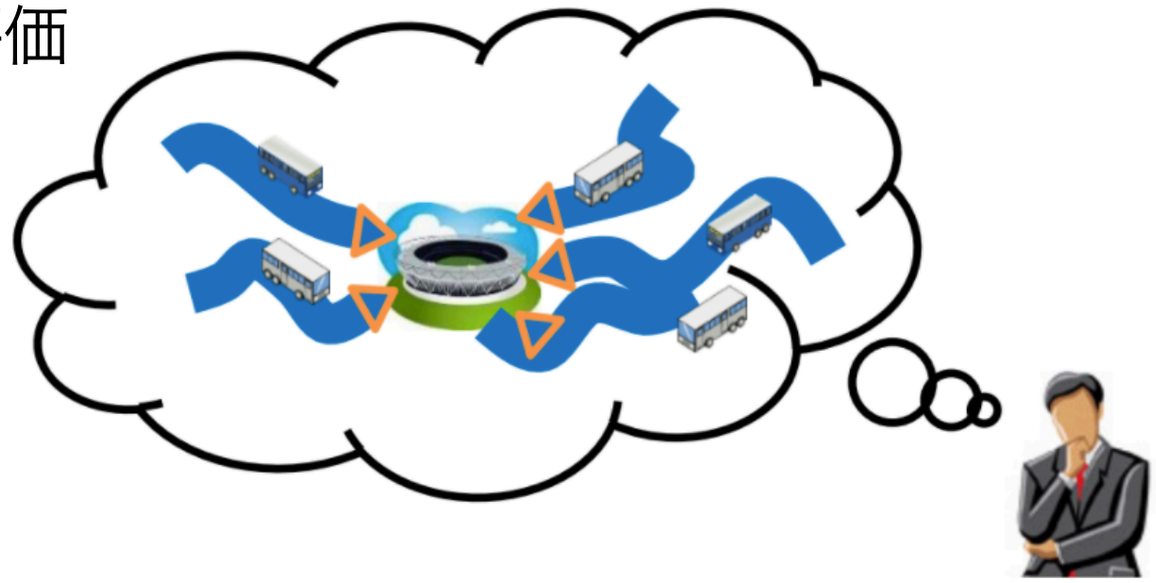


図4　路面電車延伸シミュレーション (岡山県岡山市)

提供：東京大学　藤井研究室

今日の内容

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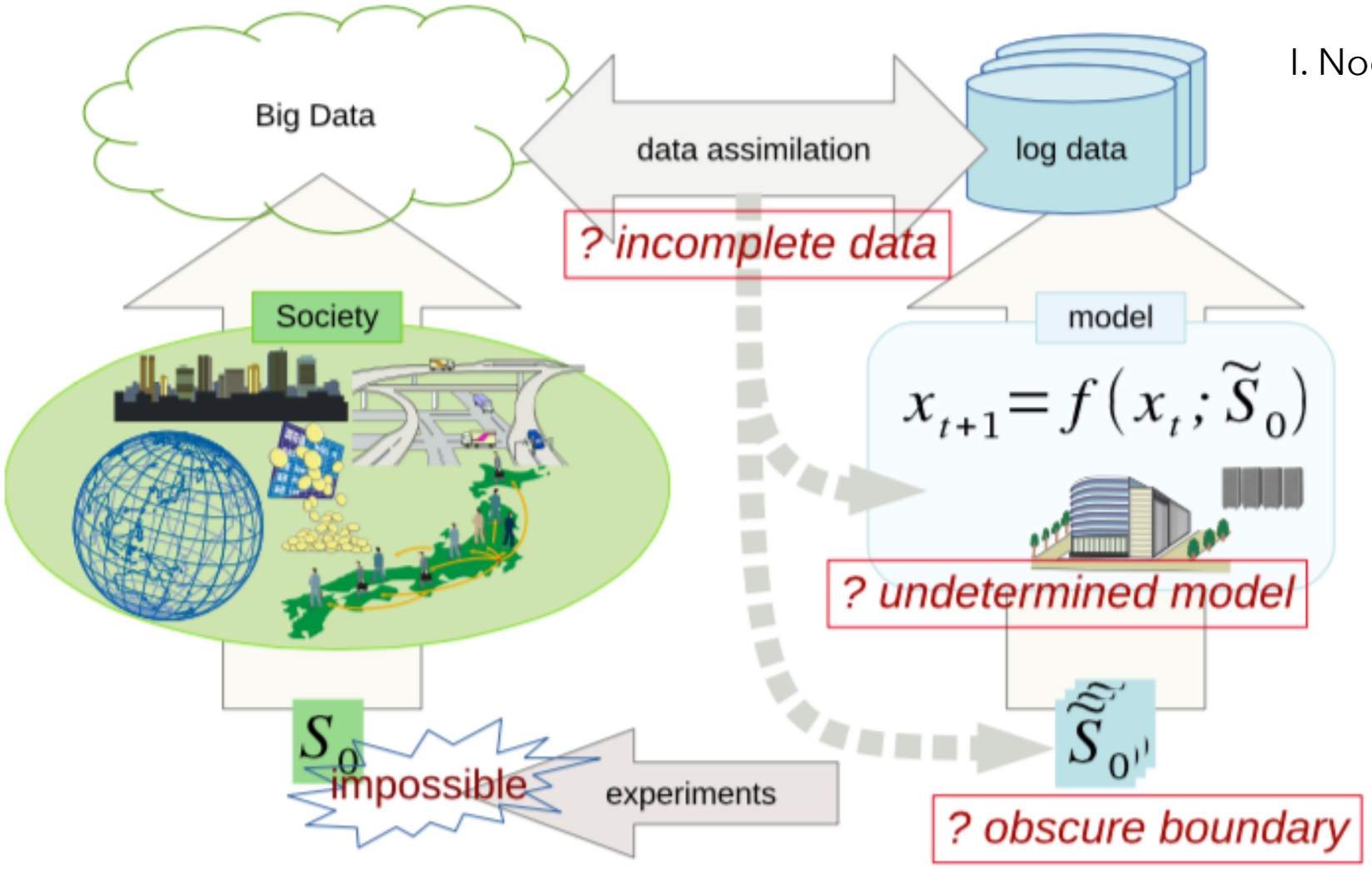
    - 「京」が考えた公共財ゲームの最強戦略

社会シミュレーションの課題

ポスト京萌芽課題「多層マルチ時空間スケール社会・経済シミュレーション技術の研究・開発」



I. Noda et al. (2015)

確立していないモデル、境界条件・初期条件の曖昧さ

→様々な条件・仮定のもとで大域的な情報を得たい

社会現象

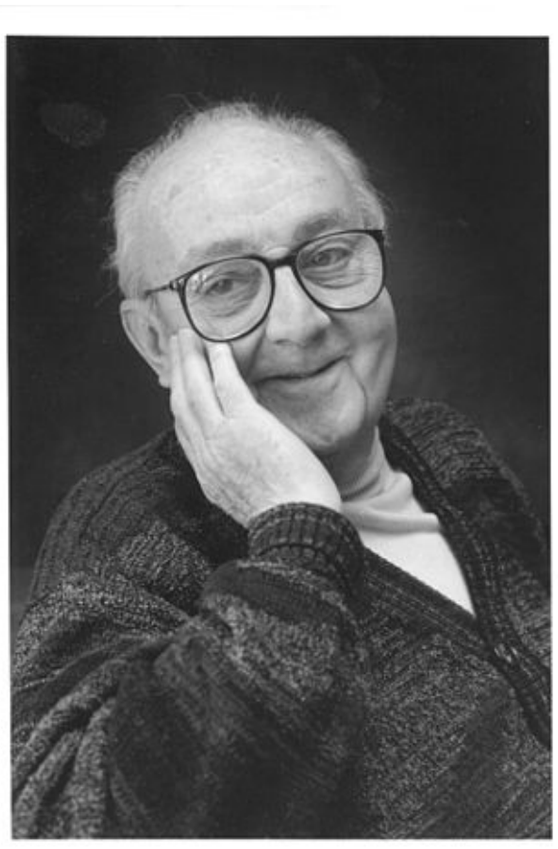
　確立した第一原理がなく、様々な要因が絡みあう

モデル構築のためには

　様々な仮定のもとでモデルを試し

　現象を再現するのに重要な要因を取捨選択

"All models are wrong, but some are useful"



By DavidMCEddy at en.wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=14941622

Typical workflow

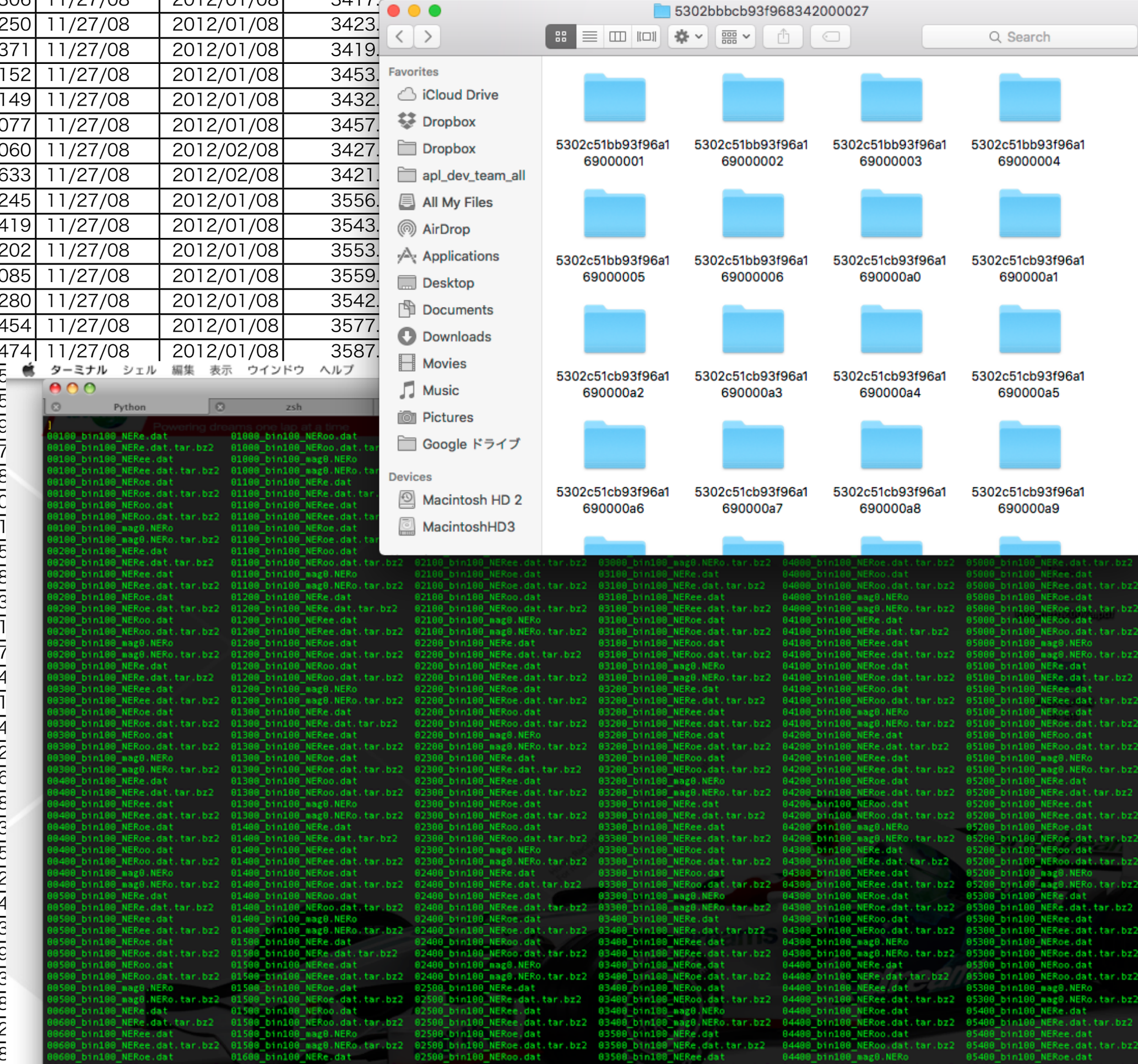
```
consider a model()
write a source code()
write a script for analysis()

while ( necessary ) {
  select a suitable parameter sets()
  execute simulation run using the parameters()
  take a note to remember what I am doing()
  wait for completion of the simulation run()
  transfer the output files to suitable folders()
  keep a note to remember what is done()
  analyze data()
  create a graph()
}

write a paper()
present in a meeting()
```

essential in research activities

tend to be a bottleneck

- comparison of many models, parameters, jobs…
- prone to human-errors
- iteration can be longer as the amount of computation grows

266	finished	212130250	11/27/08	2012/01/08	3423.
267	finished	2013371371	11/27/08	2012/01/08	3419.
268	finished	1530956152	11/27/08	2012/01/08	3453.
269	finished	168441149	11/27/08	2012/01/08	3432.
270	finished	443614077	11/27/08	2012/01/08	3457.
271	finished	1482342060	11/27/08	2012/02/08	3427.
272	finished	1953736633	11/27/08	2012/02/08	3421.
273	finished	479668245	11/27/08	2012/01/08	3556.
274	finished	2086791419	11/27/08	2012/01/08	3543.
275	finished	867116202	11/27/08	2012/01/08	3553.
276	finished	462195085	11/27/08	2012/01/08	3559.
277	finished	67364280	11/27/08	2012/01/08	3542.
278	finished	1383946454	11/27/08	2012/01/08	3577.
279	finished	1641077474	11/27/08	2012/01/08	3587.
280	finished	7034055			
281	finished	1159555			
282	finished	2128949			
283	finished	16745927			
284	finished	12679788			
285	finished	1110656C			
286	finished	17611721			
287	finished	869195			
288	finished	21118888			
349	finished	10308633			
350	finished	9017931			
351	finished	3551977			
352	finished	16176314			
353	finished	20716631			
354	finished	16664604			
355	finished	20731822			
356	finished	14237846			
357	finished	16911158			
358	finished	5043763			
359	finished	3064515			
360	finished	11094772			
361	finished	9133684			
362	finished	13812103			
363	finished	7503359			
364	finished	7984073			
365	finished	17157828			
366	finished	19281172			
367	finished	16146248			



大量のディレクトリ

毎回SSHが要求される

バグが見つかったら
今までの手順をやり直し

数ヶ月後、何をやったか
わからない

OACIS

Organizing Assistant
for Comprehensive and Interactive Simulations

OACIS Simulators Runs Analyses Hosts Logs Document

Simulators

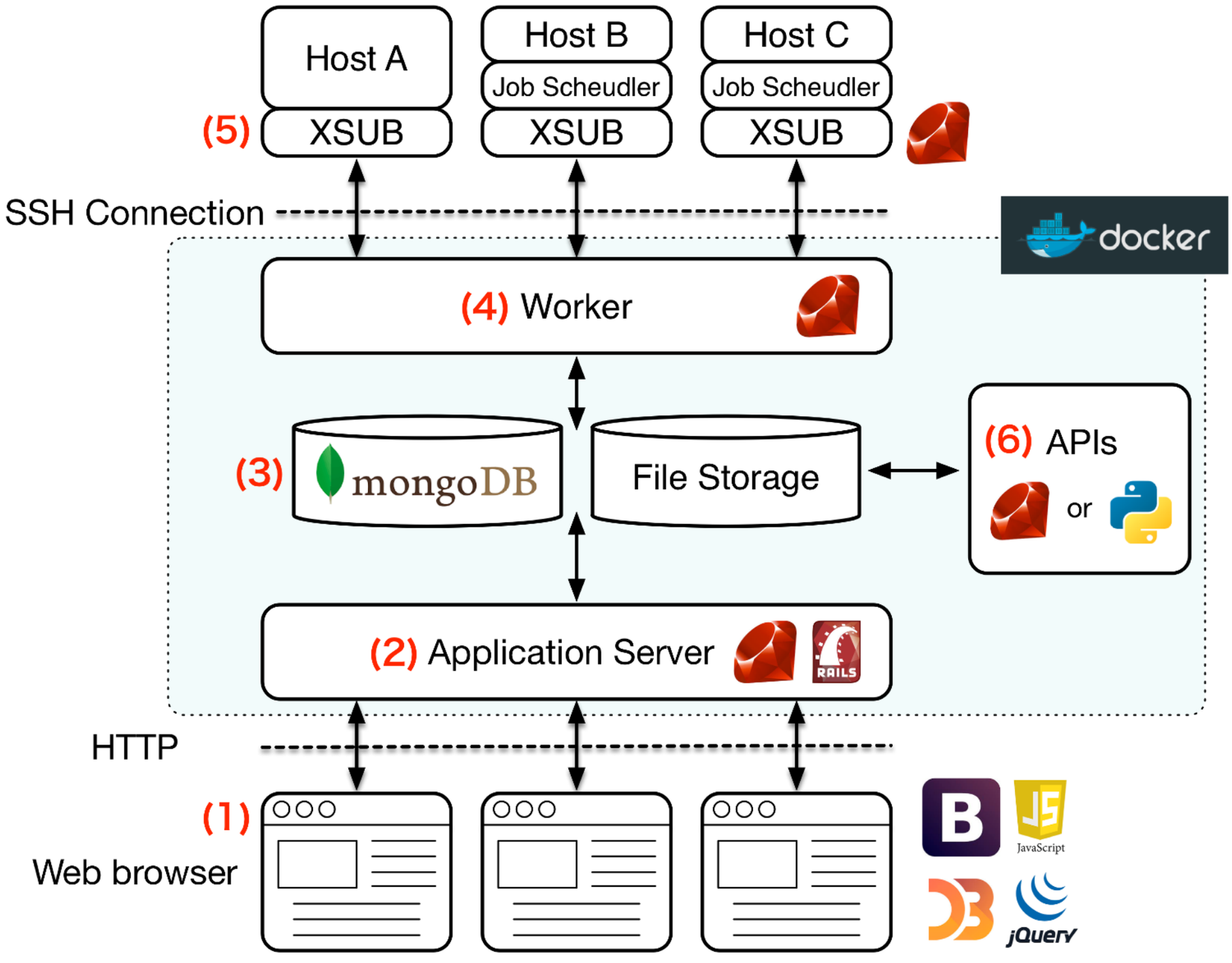
Name	Updated_at	Progress
ising2d	almost 2 years ago	100%
ising2d_2	almost 2 years ago	100%
ising_square	6 months ago	100%
1d_graph_model	almost 2 years ago	100%
niche_dynamical_graph_model	almost 2 years ago	100%
niche_dg_mod		00%
predator_prey		00%
kumpula_mod		00%
kumpula_mod		00%
kumpula_parti		00%
kumpula_copy		00%
kumpula_copy_and_shuffle_max	over 1 year ago	100%
kumpula_2d_multi_layer	over 1 year ago	100%

Available as an Open-Source software under the MIT license
https://github.com/crest-cassia/oacis

developed by Discrete-Event Simulation Research Team, AICS

System Overview

Ruby on Rails + MongoDB, Unix-based OS



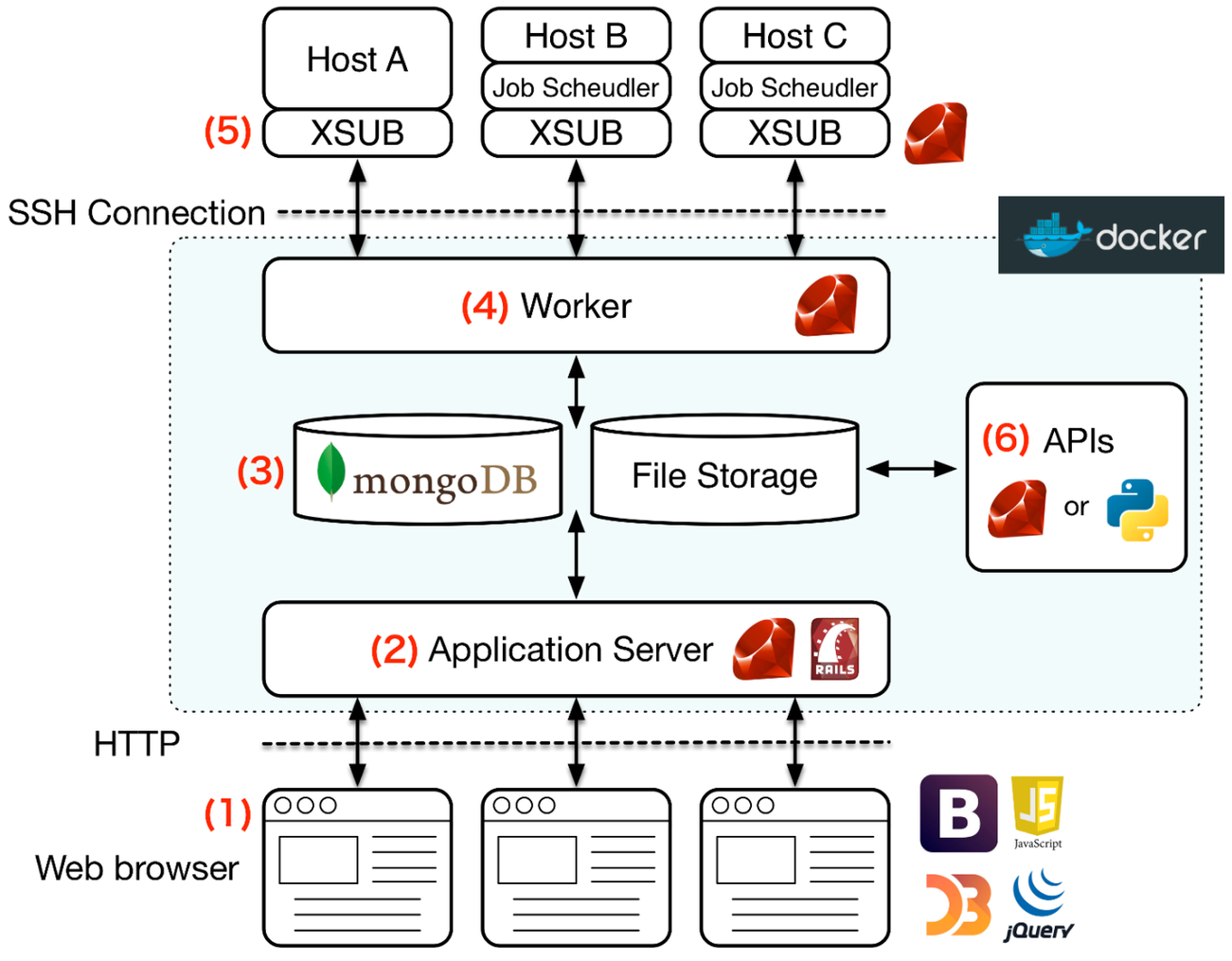
software stack

dependent on open-source frameworks and libraries

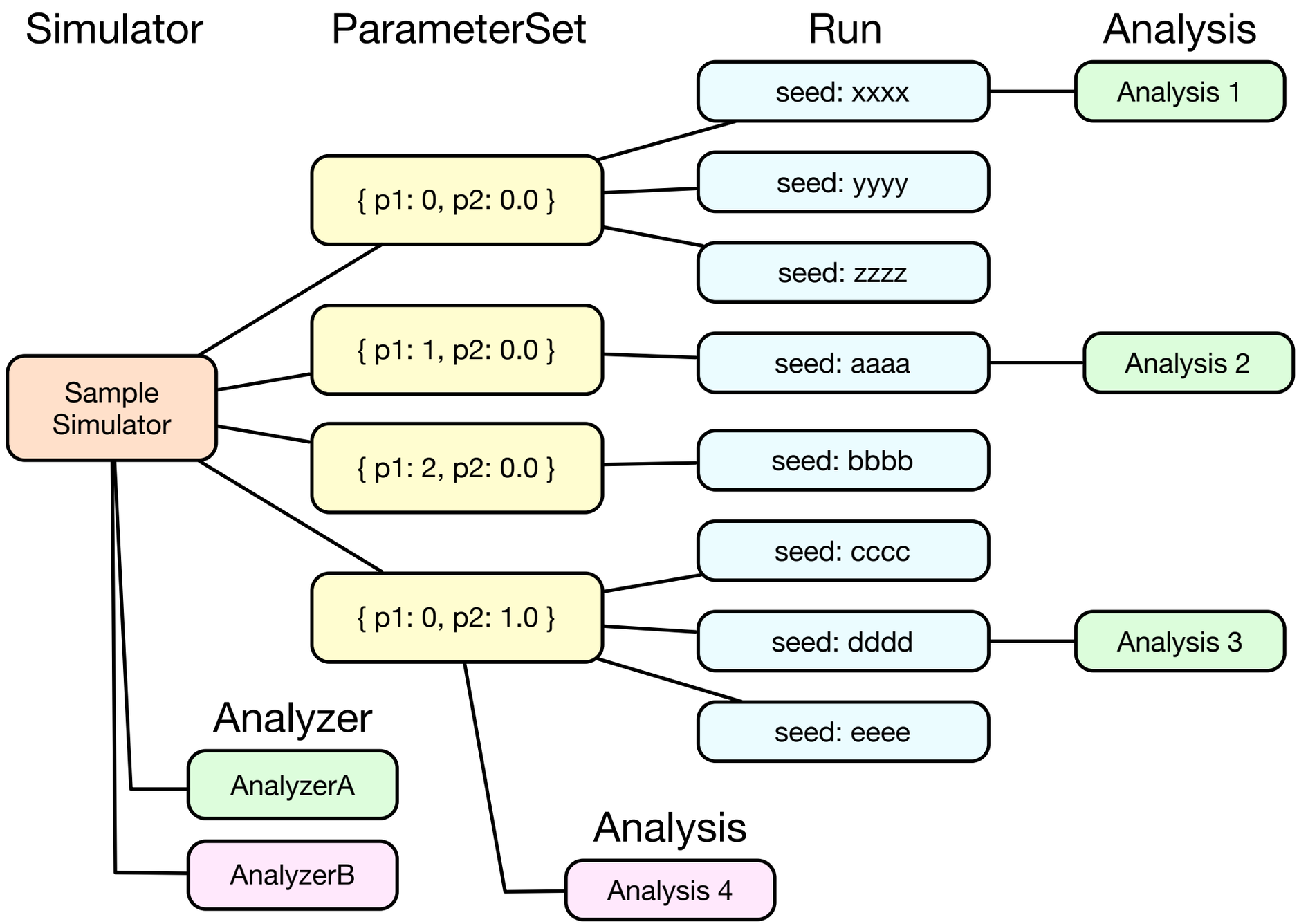
- Ruby, Python, JavaScript
- Ruby on Rails
- MongoDB
- docker
- ....

~ 13000 lines for application

~ 12000 lines for tests



Data-structure overview



DEMO

Command-line based execution

dynamical_graph

About | Parameter Sets | Progress

SimulatorDescription

Duplicate | Edit | Destroy | Show in JSON

About

Parameter Input Type	
Support MPI	
Support OMP	
Sequential Seed	
Executable On	

Defined Parameters

	Type	Default	Descripti
p	Float	0.2	probabili
t_init	Integer	1024	initializati
t_measure	Integer	65536	measure

Commands

- Pre-process Script
- Simulation Command

```
~/work/dynamical_graph_model/run.sh
```

bash script

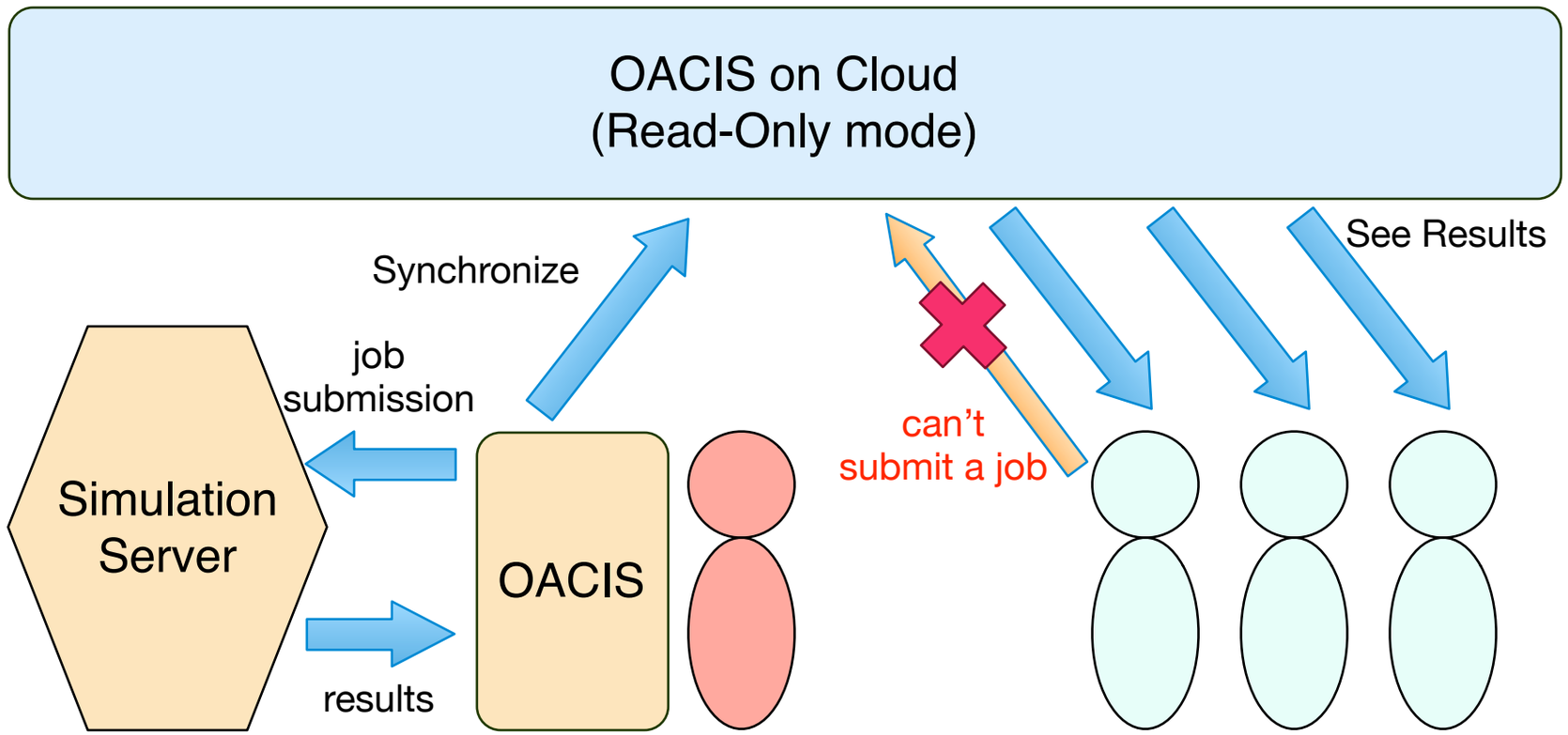
```
#!/bin/bash
export LANG=C
export LC_ALL=C

# VARIABLE DEFINITIONS ------------
export OACIS_JOB_ID=573f38c36b696d07093a0200
export OACIS_IS_MPI_JOB=false
export OACIS_MPI_PROCS=1
export OACIS_OMP_THREADS=1
OACIS_PRINT_VERSION_COMMAND="cd ~/work/dynamical_graph_model; git describe --always"

# PRE-PROCESS ---------------------
if [ `basename $(pwd)` != ${OACIS_JOB_ID} ]; then  # for manual submission
  mkdir -p ${OACIS_JOB_ID} && cd ${OACIS_JOB_ID}
  if [ -e ../${OACIS_JOB_ID}_input.json ]; then
    \mv ../${OACIS_JOB_ID}_input.json ./_input.json
  fi
fi
echo "{" > ../${OACIS_JOB_ID}_status.json
echo "  \"started_at\": \"`date`\"," >> ../${OACIS_JOB_ID}_status.json
echo "  \"hostname\": \"`hostname`\"," >> ../${OACIS_JOB_ID}_status.json

# PRINT SIMULATOR VERSION ---------
if [ -n "$OACIS_PRINT_VERSION_COMMAND" ]; then
  (eval ${OACIS_PRINT_VERSION_COMMAND}) > _version.txt
fi

# JOB EXECUTION -------------------
export OMP_NUM_THREADS=${OACIS_OMP_THREADS}
{ time -p { ~/work/dynamical_graph_model/run.sh 0.002 1048576 33554432 1471364291; }
RC=$?
echo "  \"rc\": $RC," >> ../${OACIS_JOB_ID}_status.json
echo "  \"finished_at\": \"`date`\"" >> ../${OACIS_JOB_ID}_status.json
echo "}" >> ../${OACIS_JOB_ID}_status.json

# POST-PROCESS --------------------
if [ -d _input ] && [ $RC -eq 0 ]; then {
  \rm -rf _input
} fi
```

A command is embedded into a shell script.

We can implement simulators in any language.

Sharing data

- To share the data, we provide “read-only” mode.
  - To share data, you may prepare another read-only instance.



Each simulation result and plot has an URL.

APIs

OACISの操作を自動化するため、PythonとRubyのAPIを提供

```ruby
sim = Simulator.where(name: "my_simulator").first
host = Host.where(name: "localhost").first

p1_values = [1.0,2.0,3.0,4.0,5.0]
p2_values = [2.0,4.0,6.0,8.0,10.0]

p1_values.each do |p1|
  p2_values.each do |p2|
    parameter = {"p1"=>p1,"p2"=>p2}
    ps = sim.find_or_create_parameter_set( parameter )
    ps.find_or_create_runs_upto(5, submitted_to: host)
  end
end
```

loop on parameter “p1”

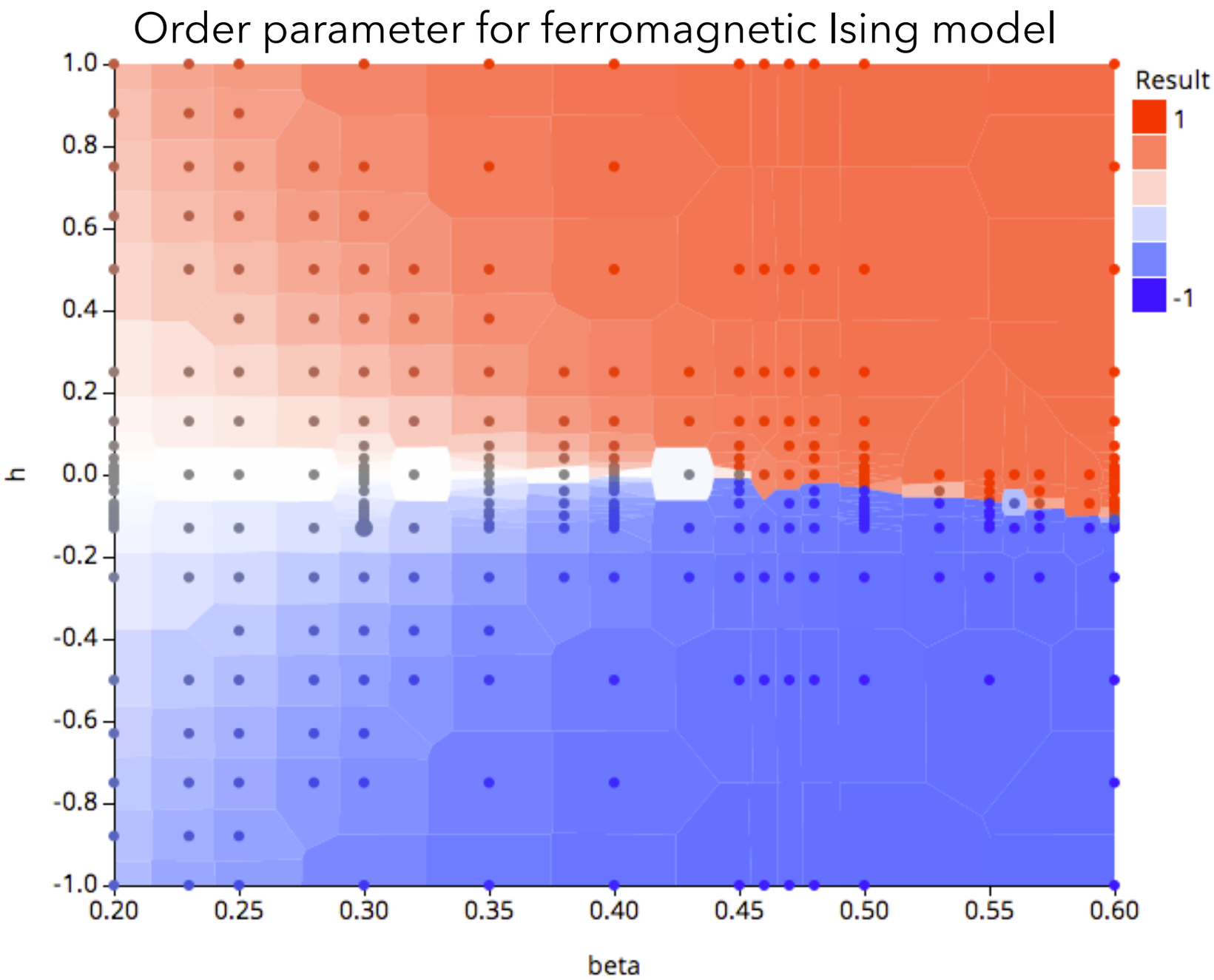
loop on parameter “p2”

creation of PS and Runs

ジョブの完了時に呼ばれる非同期処理も定義可能（coroutineを使う）

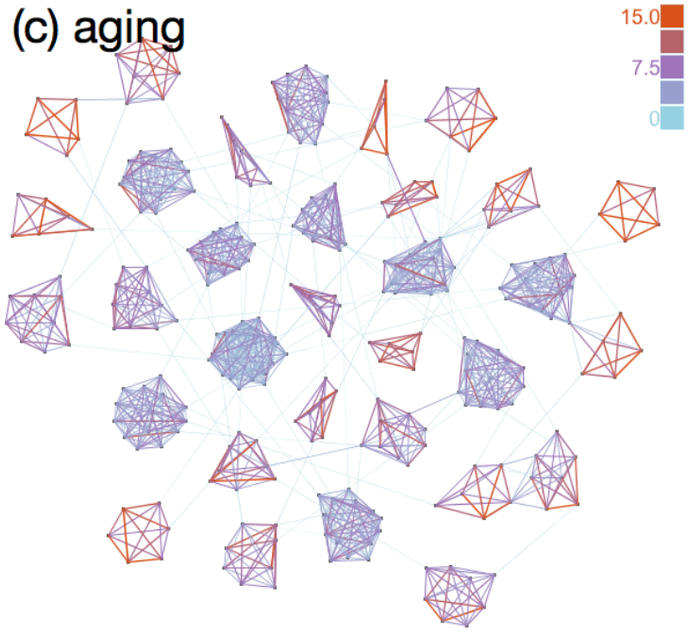
実行結果に応じて次のパラメータ探索範囲を能動的に決める

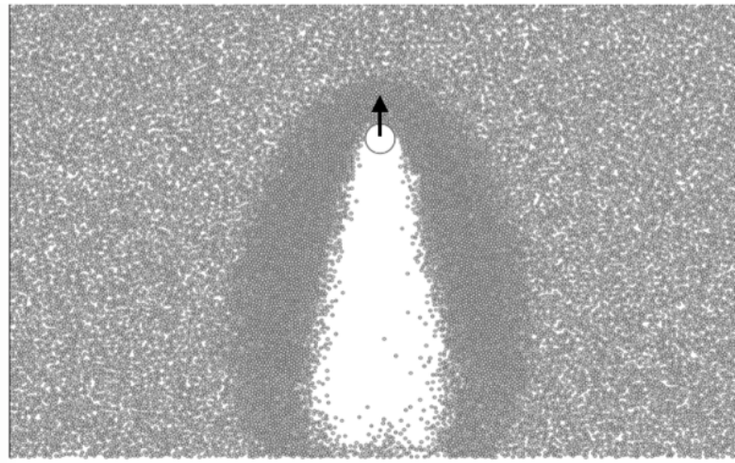
APIの利用例

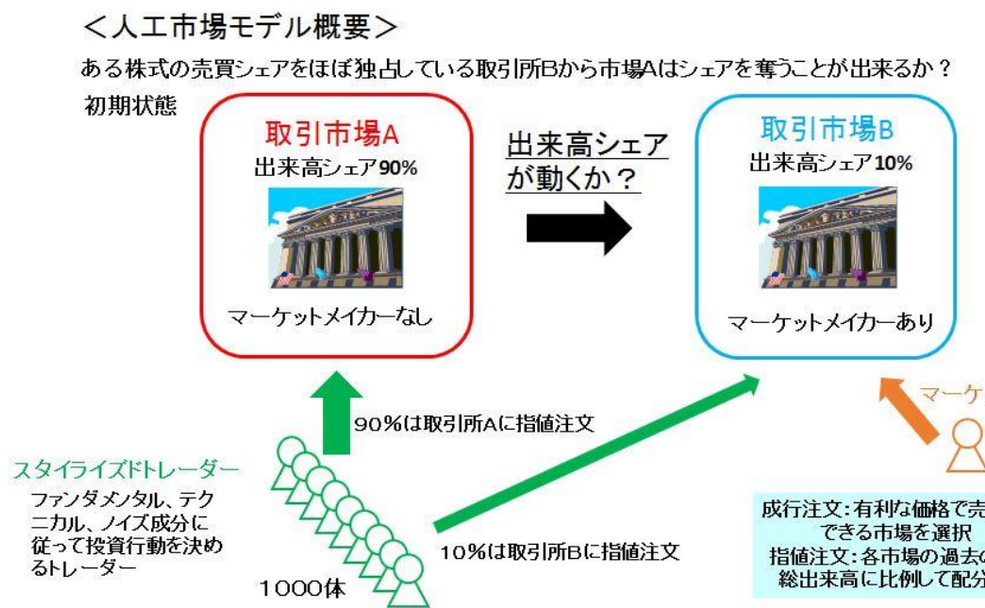

Order parameter for ferromagnetic Ising model
Result
1
-1
h
beta
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60

Use cases

- modeling social networks
  - Y. Murase et al. (2014,2015), Torok et al.(2016), Jo et al. (2016)
- agent-based simulation of stock markets
  - Kusada et al. (2014), Torii et al. (2015)
- agent-based simulation of traffic and pedestrians
  - Matsushima(2016), Tsuji(2015), Uchitane et al.(2016), Yoshioka et al.
- studies on open evolving systems
  - Shimada et al. (2014,2015), Murase et al.(2015)
- molecular dynamics simulation of granular material
  - Kuwabara et al.(2016)
- first-principle calculation of condensed matter physics
  - Lam et al.(2017)
- simulation of rescue robots
  - Takayanagi et al. (2016), Takami et al. (2017)







事例紹介 1

NIMSの研究プロジェクト

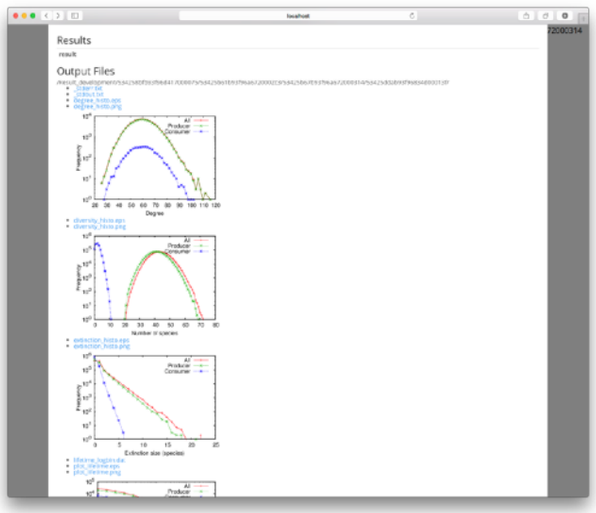
P.T. Lam et al. (2017)

物性第一原理計算を様々な（約656種）の化合物に対して網羅的に行う
収束計算を行うが、収束に失敗したらパラメータを変更して再実行

APIによる実行

```
{"material A": [
        {"p1": ..., "p2": ..., "p3": ...},
        {"p1": ..., "p2": ..., "p3": ...},
        {"p1": ..., "p2": ..., "p3": ...},
         ....
        ],
  "material B": [
        .....
        ]
  "material C": ...
```

手動による実行



604種の計算に成功。

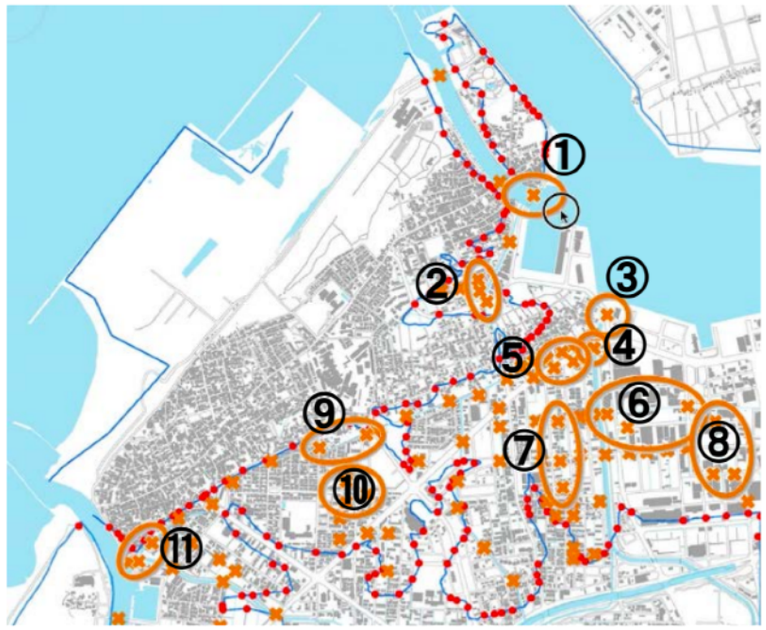
（残り52種については手動で調整しても収束せず）

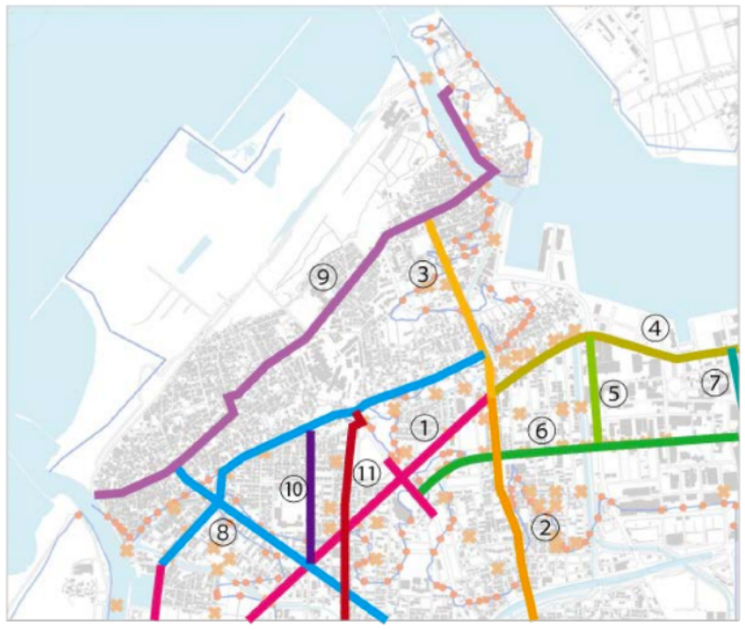
Application: Evacuation from Tsunami

すべての施作を施すのは現実的ではない。
どの施作が結果に重要な影響を与えるか評価（感度解析）

Tsuji et al (2015)

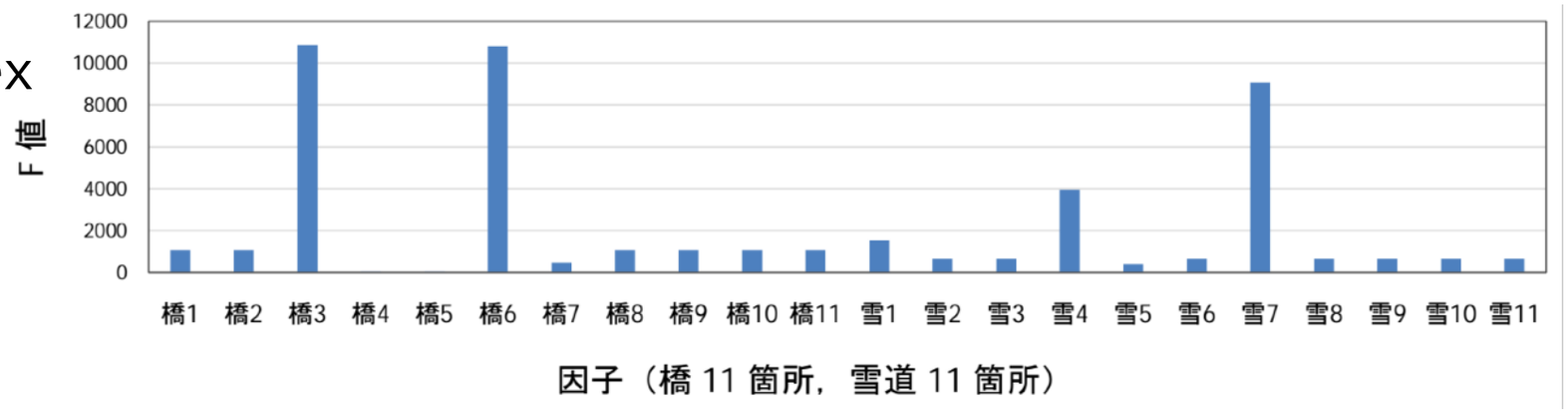
AIST
NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)





金沢市大野町で実施された「逃げ地図ワークショップ」で決定

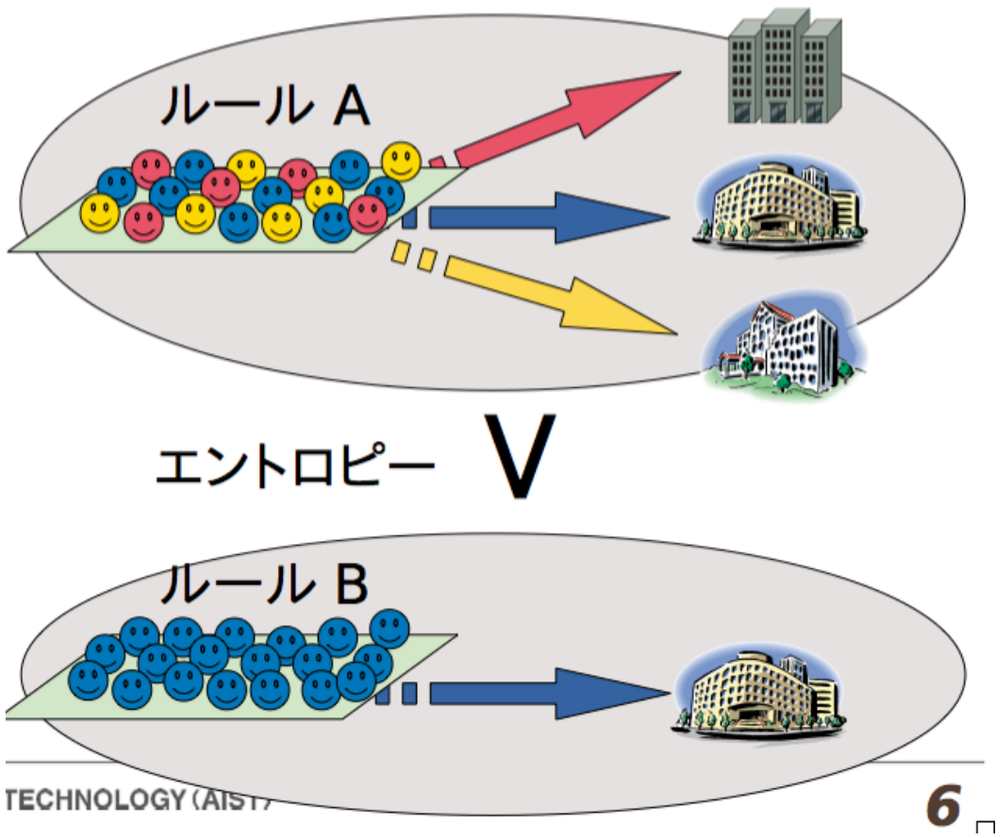
sensitivity index



input factors

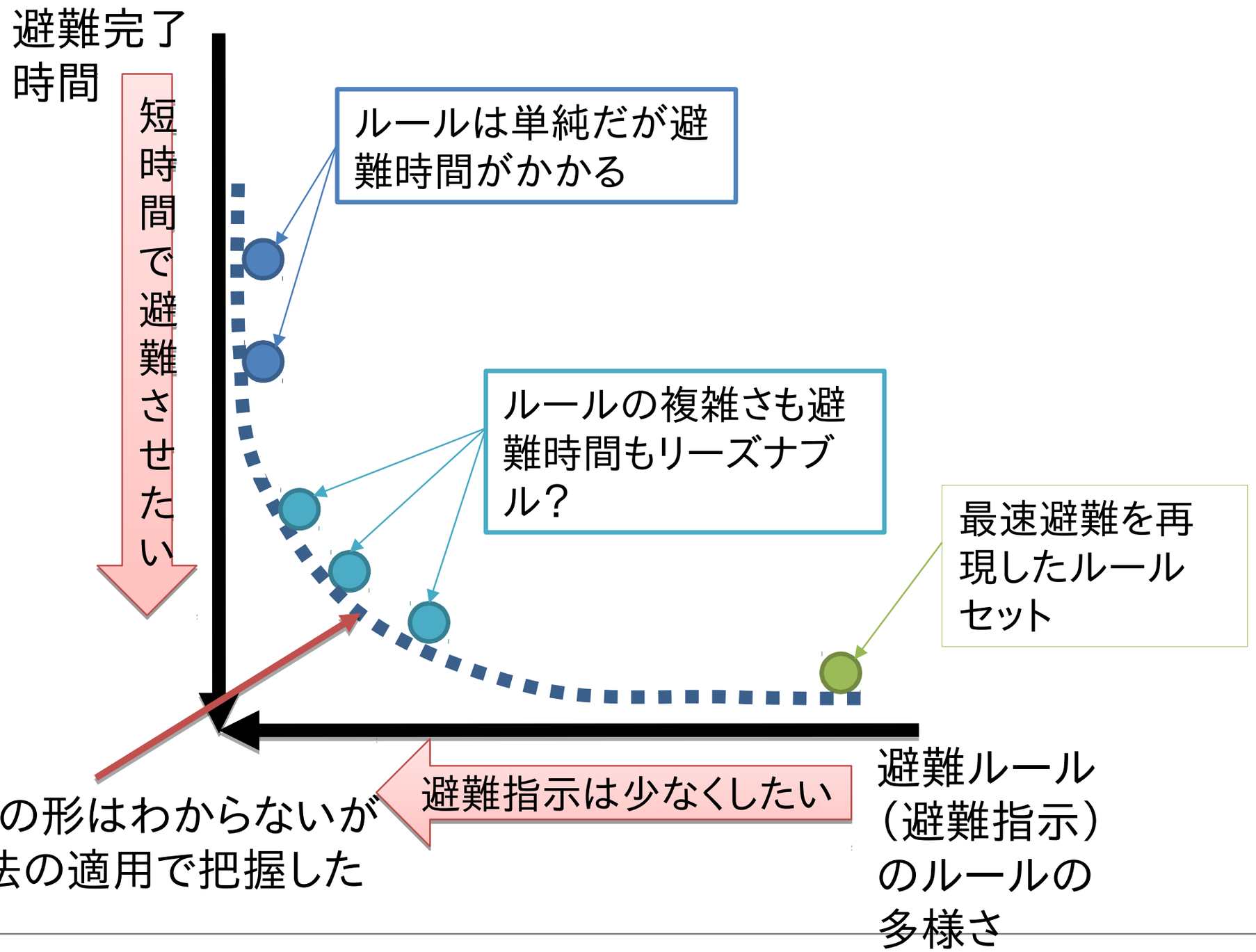
アプリケーション事例

- 評価軸:
  - 避難時間
  - 避難誘導ルールの複雑さ
    - ＝同じ地区の逃げ方のバリエーションの多さ
      ＝同じ地区からのの異なる逃げ方の
      人数比の情報エントロピー



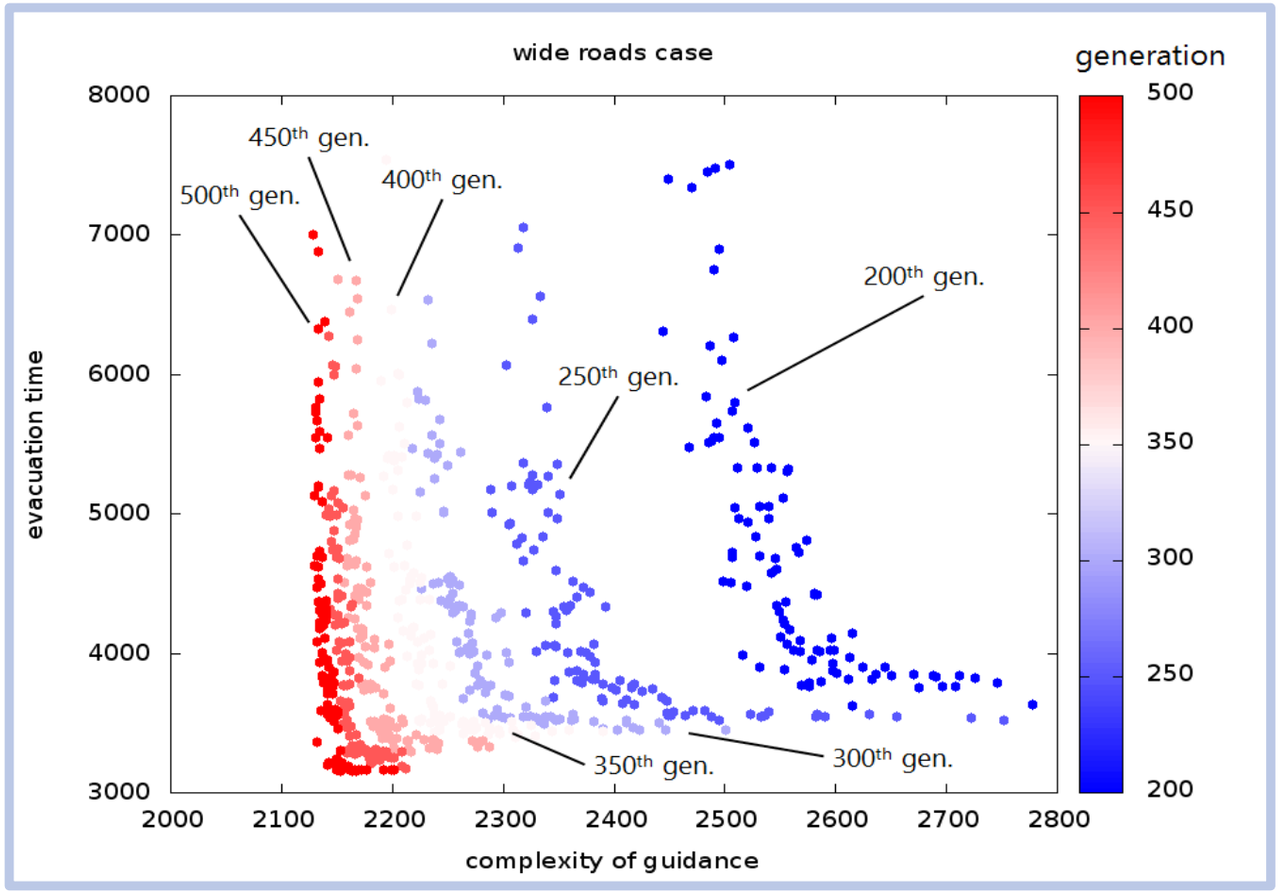
避難時間と避難指示

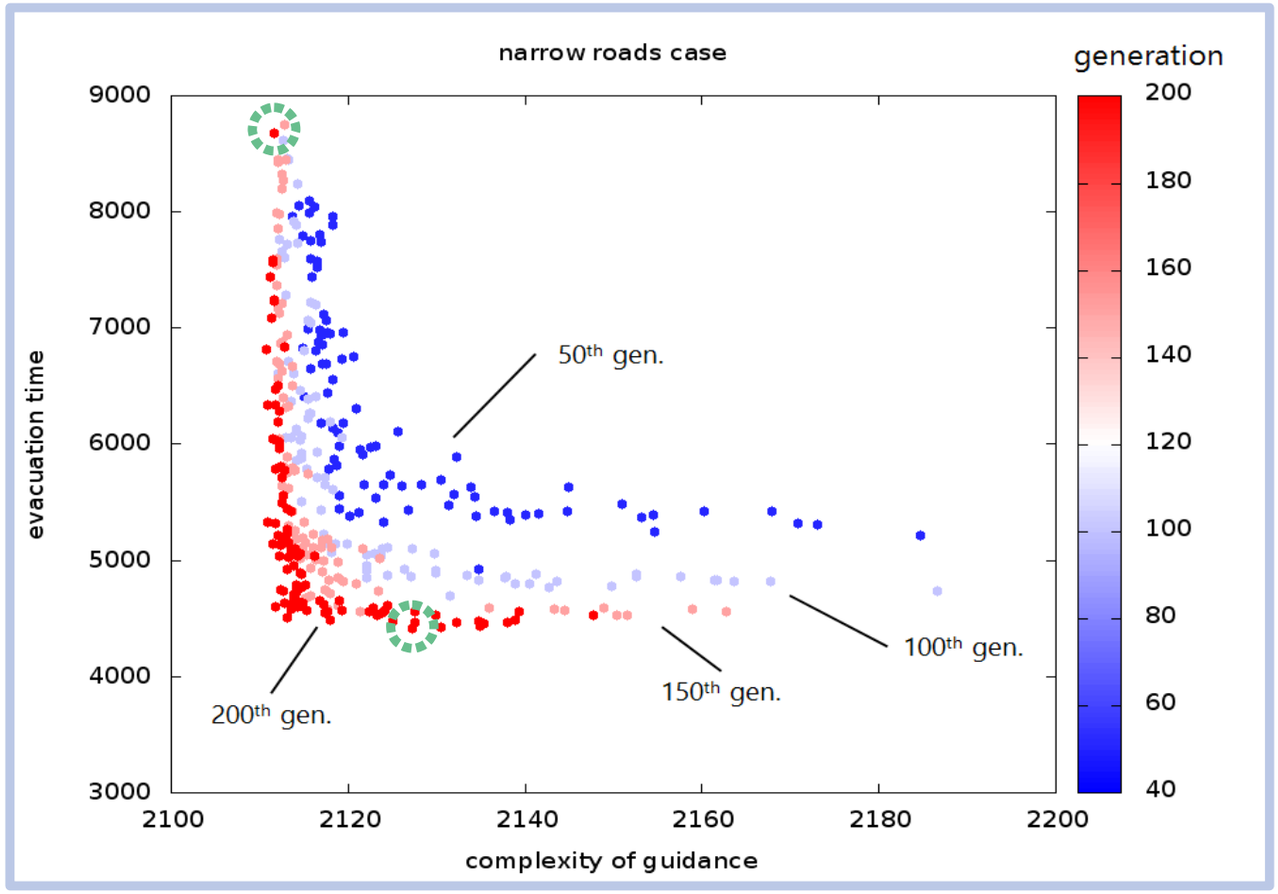
●パレート最適なトレードオフ面を探したい



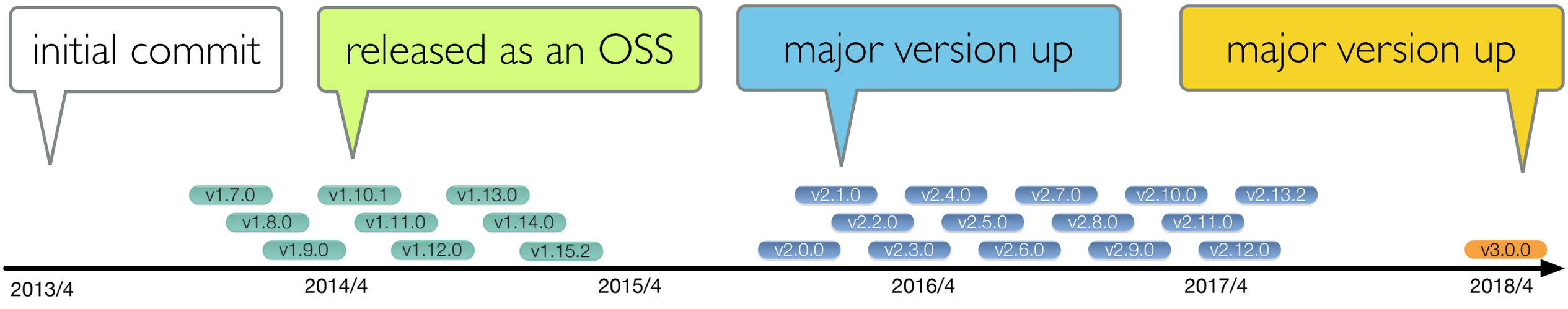
世代交代とパレート解

- 大阪市淀川区での避難
  - 車道も使ったシミュレーション(wide)
  - 歩道のみのシミュレーション(narrow)

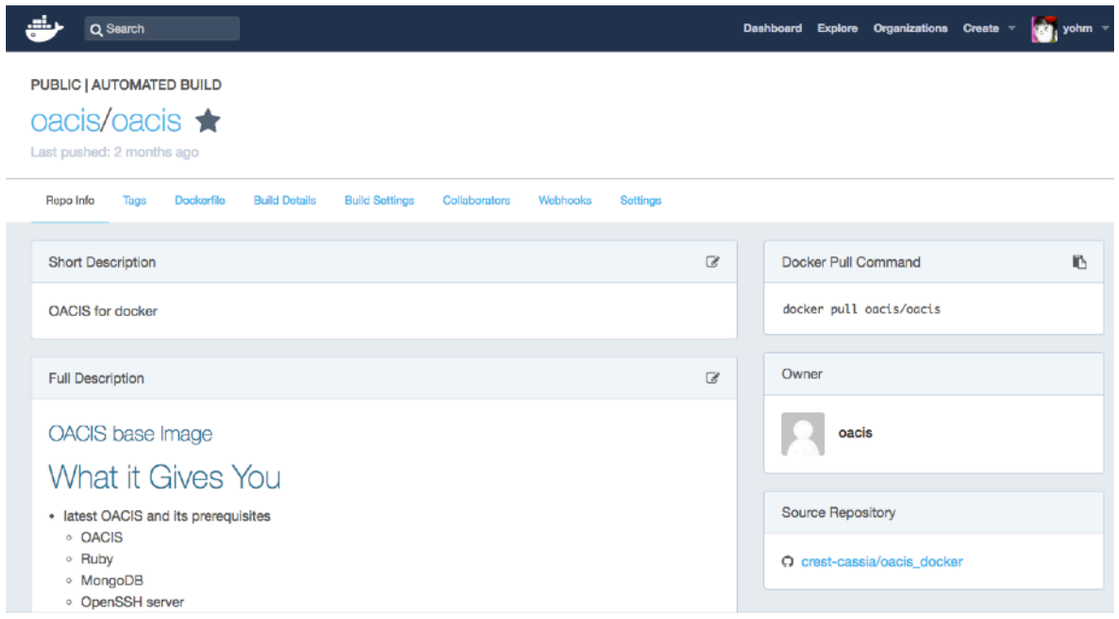




Development History



- UIの大幅な改善
- 継続的なバグフィックス
- パフォーマンス改善
- ポスト処理の遠隔実行
- async/await APIの提供
- dockerイメージの提供
- PythonでのAPIの提供



ぜひ使ってみてください！

フィードバック、バグ報告、プルリク歓迎

今日の内容

- 社会シミュレーションとは？
- 網羅的探索のためのフレームワーク
- ゲーム理論の研究紹介
    - 「京」が考えた公共財ゲームの最強戦略

Successful strategies in the Tragedy of the Commons

Yohsuke Murase, Seung Ki Baek

RIKEN Center for Computational Science, Japan
Pukyong National University, Korea

Y. Murase, S.K. Baek, J. Theor. Biol. **449** p94 (2018)

iterated Prisoner's Dilemma

	cooperation	**defection**
cooperation	(3,3)	(0,5)
defection	(5,0)	(1,1)

implementation error occurs with probability e

long-term payoff

$$f_i \equiv \lim_{e \to 0} \lim_{T \to \infty} \frac{1}{T} \sum_{t=0}^{T-1} F_i^{(t)}$$

Social Dilemmas

- Situations where any individual may profit from selfishness unless too many individuals choose the selfish option, in which case the whole group loses.

The tragedy of the commons

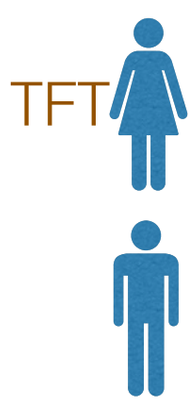
- Resource depletion
- Pollution
- Over grazing
- Over fishing
- Traffic jam
- …

How can cooperation emerge and be stable?

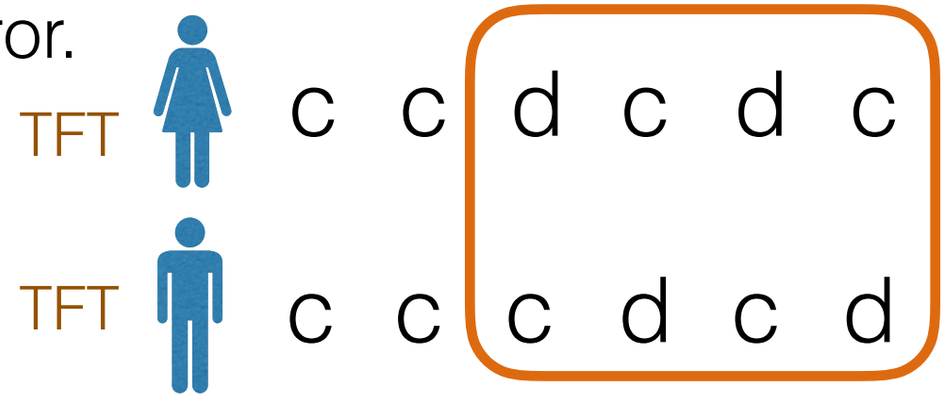
Tit-For-Tat

Copy the co-player's previous move.

It is guaranteed that your payoff is no less than the co-players'.

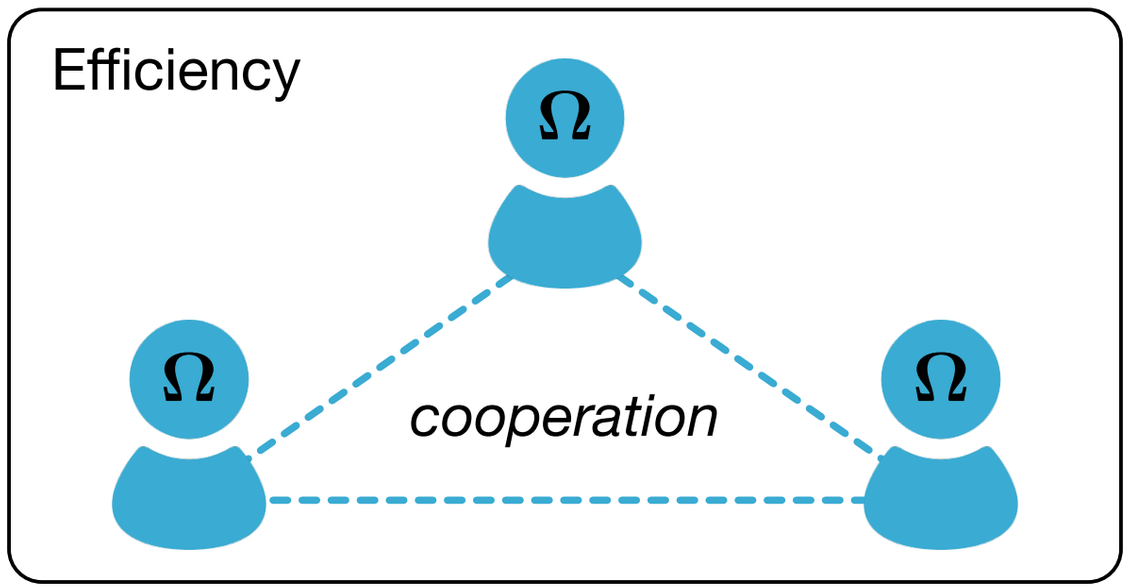


Cooperation is fragile against an error.

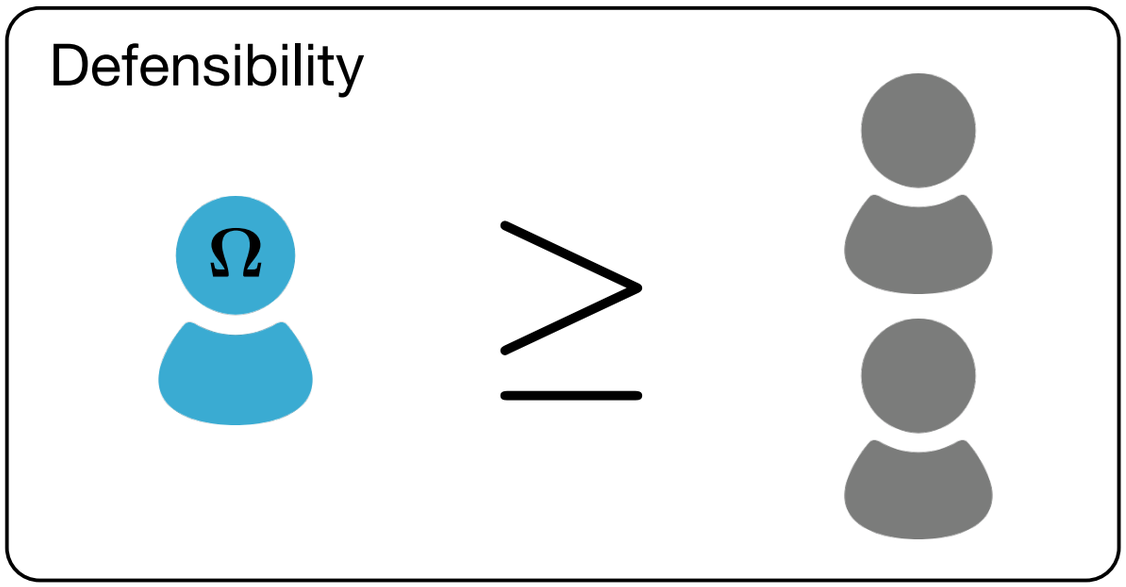


It cannot exploit naive cooperator.

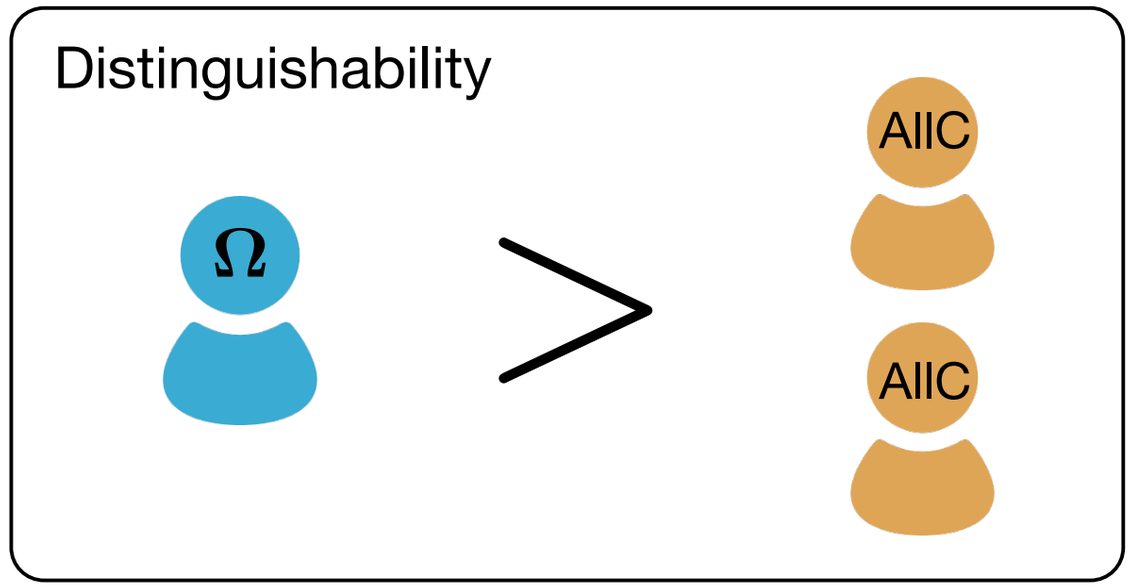
three conditions for successful strategies



WSLS

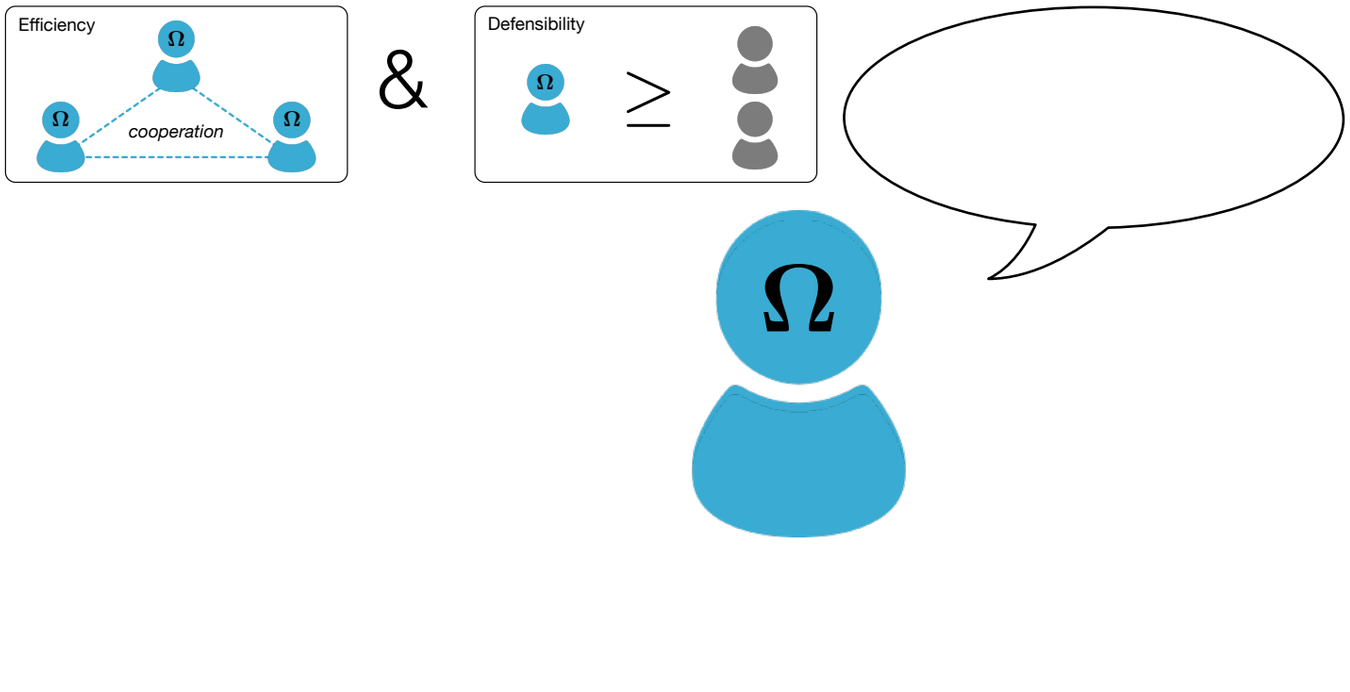


TFT



WSLS

form a cooperative Nash-equilibrium

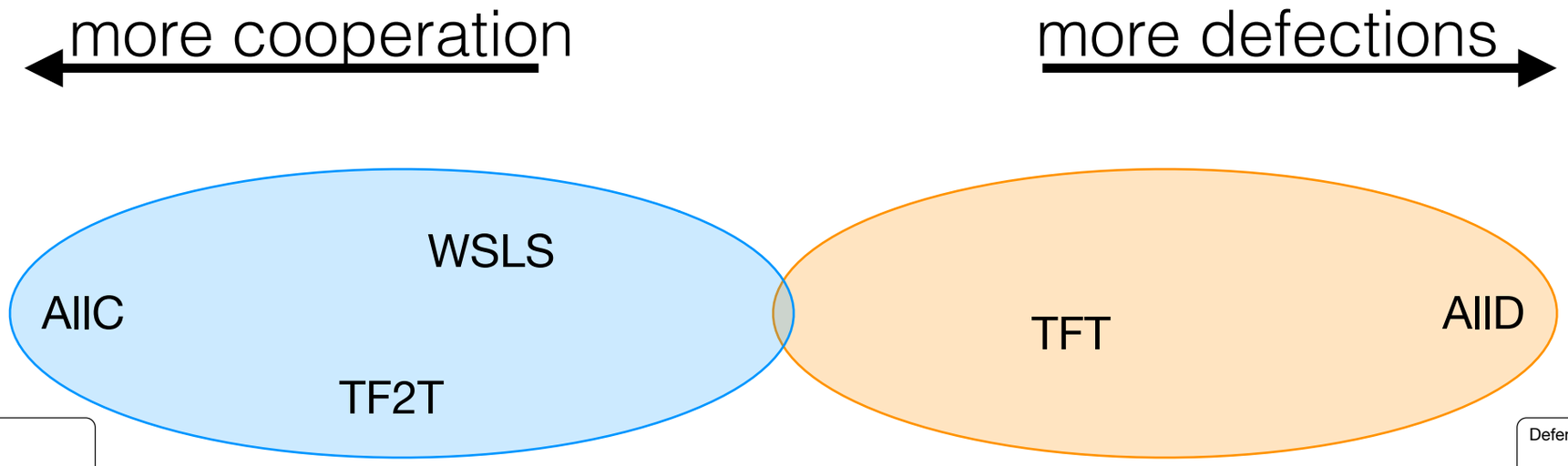


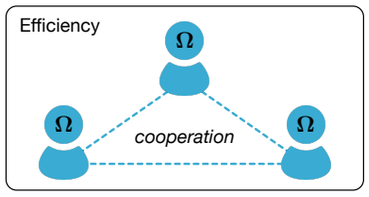
You can publicly announce your strategy.
Co-players understand it is not possible to exploit you.
The best thing the co-players can do is to take the same strategy.

=>

A cooperative Nash-equilibrium is formed.

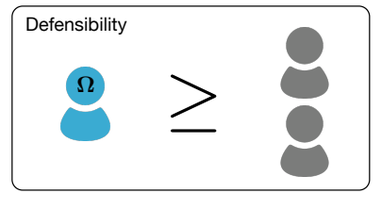
Is there a strategy satisfying these conditions simultaneously?





efficient strategies

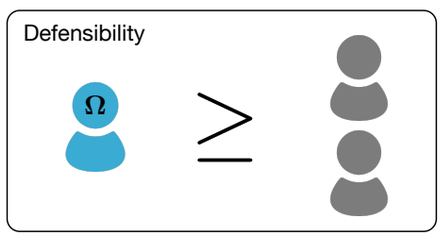
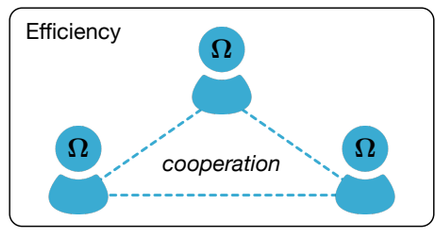
defensible strategies



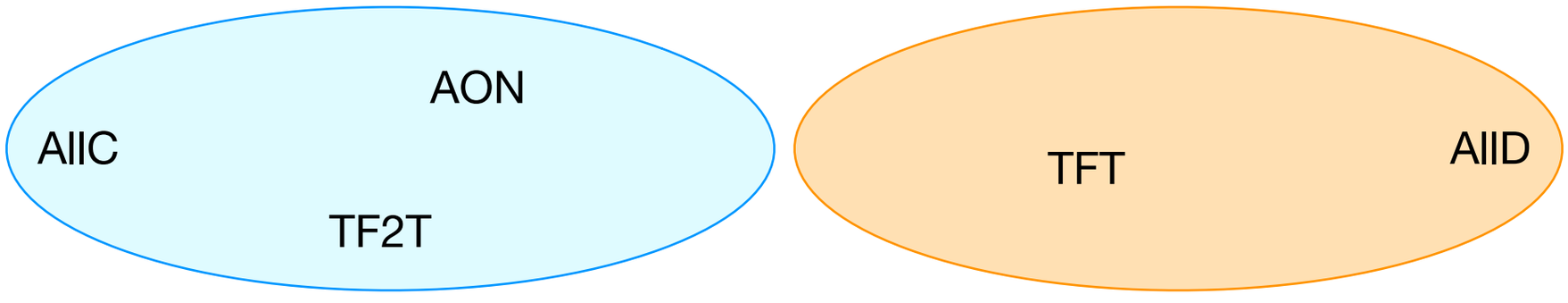
Brute-force enumeration!

- # of memory-2 strategies = 2^40

Enumeration of strategies

# of m=2 strategies		1,099,511,627,776
Defensibility against AllD		805,306,368
Defensibility		3,483,008
Efficiency		**0**

impossibility

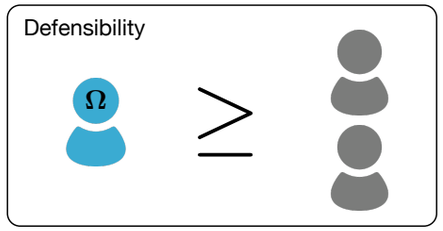
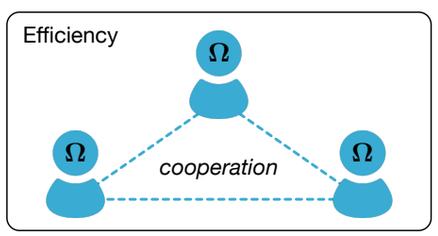
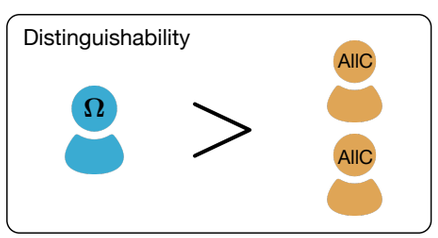


There is no defensible and efficient strategy for n=3 in memory-2 strategy space.

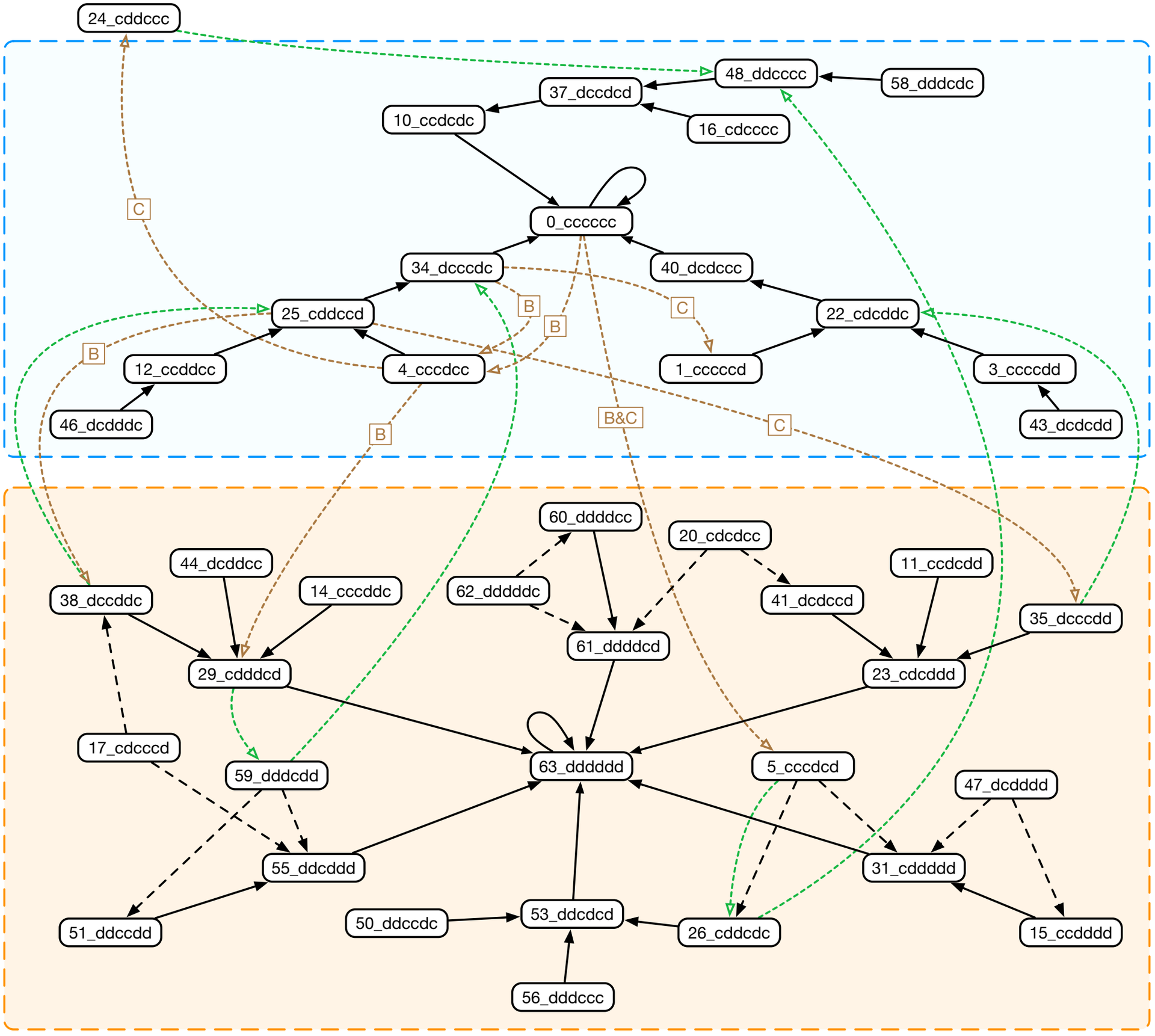
Is there no solution for the three-person game?
or
Does the solution exist in memory-3 strategies?

The number of m=3 strategies : $2^{288} \approx 5 \times 10^{86}$

Enumeration of strategies

# of m=2 strategies		1,099,511,627,776
Defensibility against AllD		805,306,368
Defensibility		3,483,008
"Partial" Efficiency ($p_{cooperation} > 0$)		544
Distinguishability		**256**

"Partially" Successful Strategies (PS2)


24_cddccc
48_ddcccc
58_dddcdc
37_dccdcd
10_ccdcdc
16_cdcccc
0_cccccc
34_dcccdc
40_dcdccc
25_cddccd
22_cdcddc
12_ccddcc
4_cccdcc
1_cccccd
3_ccccdd
46_dcdddc
43_dcdcdd
C
B
B
B
C
C
B
B&C
C
60_ddddcc
20_cdcdcc
44_dcddcc
11_ccdcdd
14_cccddc
62_dddddc
41_dcdccd
35_dcccdd
38_dccddc
61_ddddcd
29_cdddcd
23_cdcddd
17_cdcccd
63_dddddd
5_cccdcd
47_dcdddd
59_dddcdd
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31_cdddddd
51_ddccdd
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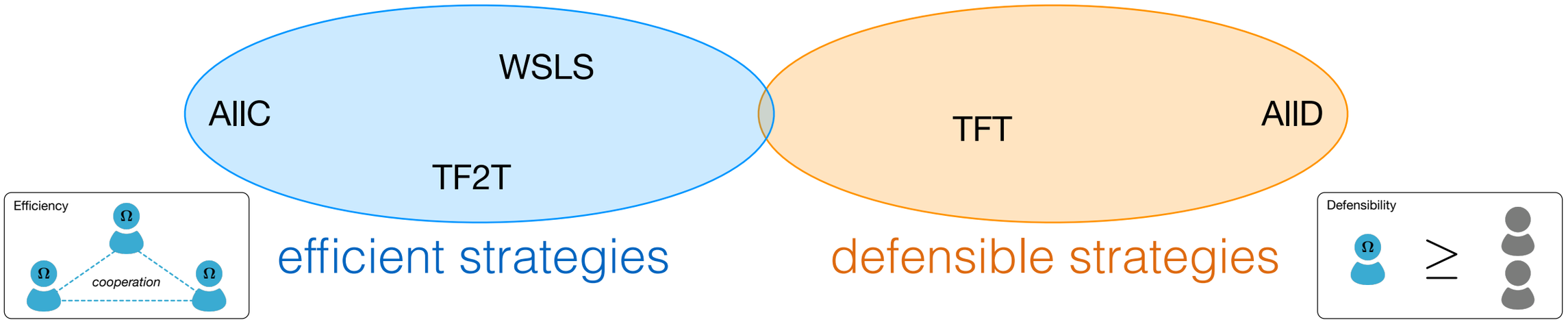
53_ddcdcd
26_cddcdc
15_ccddddd
56_dddccc



Successful strategies are found.
Mutual cooperation is reached with probability 1
while keeping the defensibility and the distinguishability.

Table 4
One of successful memory-3 strategies. We have picked up the strategy having the largest number of *c*. The left column shows the state of Bob and Charlie, whereas Alice's state is shown on the right.

$B_{t-3}B_{t-2}B_{t-1}C_{t-3}C_{t-2}C_{t-1}$	$A_{t-3}A_{t-2}A_{t-1}$							
	ccc	*ccd*	*cdc*	*cdd*	*dcc*	*dcd*	*ddc*	*ddd*
cccccc	*c*	*c*	*d*	*c*	*c*	*c*	*d*	*c*
ccccd/ccdccc	*d*	*c*	*c*	*c*	*d*	*c*	*c*	*c*
cccdc/cdcccc	*c*	*d*	*c*	*d*	*c*	*d*	*c*	*d*
cccdd/cddccc	*d*	*d*	*d*	*d*	*d*	*d*	*d*	*d*
ccdcc/dccccc	*c*	*c*	*d*	*c*	*c*	*c*	*d*	*c*
ccdcd/dcdccc	*d*	*c*	*c*	*c*	*d*	*c*	*c*	*c*
ccddc/ddcccc	*c*	*d*	*c*	*d*	*c*	*d*	*c*	*d*
ccddd/dddccc	*d*	*d*	*d*	*d*	*d*	*d*	*d*	*d*
ccdccd	*d*	*c*	*c*	*c*	*d*	*c*	*c*	*d*
ccdcdc/cdcccd	*c*	*c*	*c*	*c*	*d*	*c*	*d*	*c*
ccdcdd/cddccd	*d*	*d*	*d*	*d*	*d*	*d*	*d*	*d*
ccddc/dccccd	*d*	*c*	*c*	*c*	*d*	*c*	*c*	*c*
ccddcd/dcdccd	*d*	*c*	*c*	*d*	*d*	*c*	*c*	*d*
ccdddc/ddcccd	*d*	*c*	*d*	*c*	*d*	*c*	*d*	*c*
ccdddd/dddccd	*d*	*d*	*d*	*d*	*d*	*d*	*d*	*d*
cdccdc	*c*	*d*	*c*	*d*	*c*	*c*	*c*	*d*
cdccdd/cddcdc	*d*	*d*	*c*	*d*	*d*	*d*	*c*	*d*
cdcdcc/dcccdc	*c*	*d*	*c*	*c*	*c*	*d*	*c*	*d*
cdcdcd/dcdcdc	*d*	*c*	*d*	*c*	*d*	*c*	*d*	*c*
cdcddc/ddccdc	*c*	*d*	*c*	*d*	*c*	*d*	*c*	*d*
cdcddd/dddcdc	*d*	*d*	*c*	*d*	*d*	*d*	*c*	*d*
cddcdd	*d*	*d*	*c*	*d*	*d*	*d*	*c*	*d*
cdddcc/dcccdd	*d*	*d*	*d*	*d*	*d*	*d*	*d*	*d*
cdddcd/dcdcdd	*d*	*d*	*d*	*d*	*d*	*d*	*d*	*d*
cddddc/ddccdd	*d*	*d*	*c*	*c*	*d*	*d*	*c*	*d*
cddddd/ddddcd	*d*	*d*	*c*	*d*	*d*	*d*	*c*	*d*
dccdcc	*c*	*c*	*d*	*c*	*c*	*c*	*d*	*c*
dccdcd/dcddcc	*d*	*c*	*c*	*c*	*d*	*c*	*c*	*c*
dccddc/ddcdcc	*c*	*d*	*c*	*d*	*c*	*d*	*c*	*d*
dccddd/ddddcc	*d*	*d*	*d*	*d*	*d*	*d*	*d*	*d*
dcddcd	*d*	*c*	*c*	*d*	*d*	*c*	*c*	*d*
dcdddc/ddcdcd	*d*	*c*	*d*	*c*	*d*	*c*	*d*	*c*
dcdddd/ddddcd	*d*	*d*	*d*	*d*	*d*	*d*	*d*	*d*
ddcddc	*c*	*d*	*c*	*d*	*c*	*d*	*c*	*d*
ddcddd/dddddc	*d*	*d*	*c*	*d*	*d*	*d*	*c*	*d*
dddddd	*d*	*d*	*c*	*d*	*d*	*d*	*c*	*d*

An example of successful strategy.

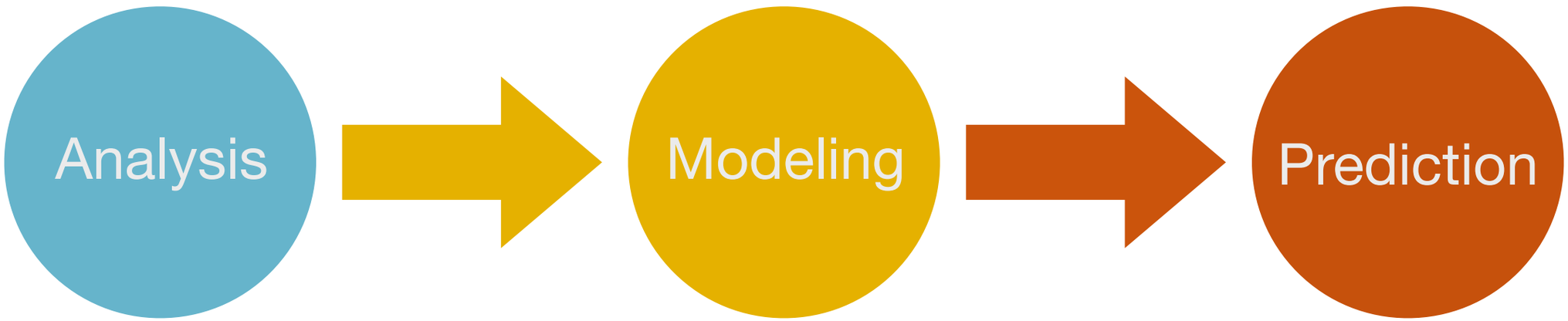
Conclusions

- 公共財ゲームにおけるジレンマを解決する方法は確かに存在する！
  - 「自分を犠牲にできるいい人」である必要はない。
  - 嫉妬深く自己中心的なプレイヤーでも、モラルに訴えかけなくても、相互協力は実現できる。
- ただしスパコンがあれば。

Y. Murase, S.K. Baek, J. Theor. Biol. **449** p94 (2018)

まとめ

観測　　モデル化・理解　　予測・制御



Big Data Internet of Things	統計モデル マルチエージェントモデル	機械学習 シミュレーション

- Big Data + Machine Learning により、計算社会科学が生まれた。
- ポスト「データサイエンス」「機械学習」としての社会シミュレーションの時代になる。
- HPCを使った網羅的アプローチが強力な手段。未開拓領域！