

可視化の世界

計算科学が拓く世界

2016年10月19日（水）

学術情報メディアセンター

小山田耕二

内容

- 可視化について
- 可視化事例
- 因果推論技術
- 課題

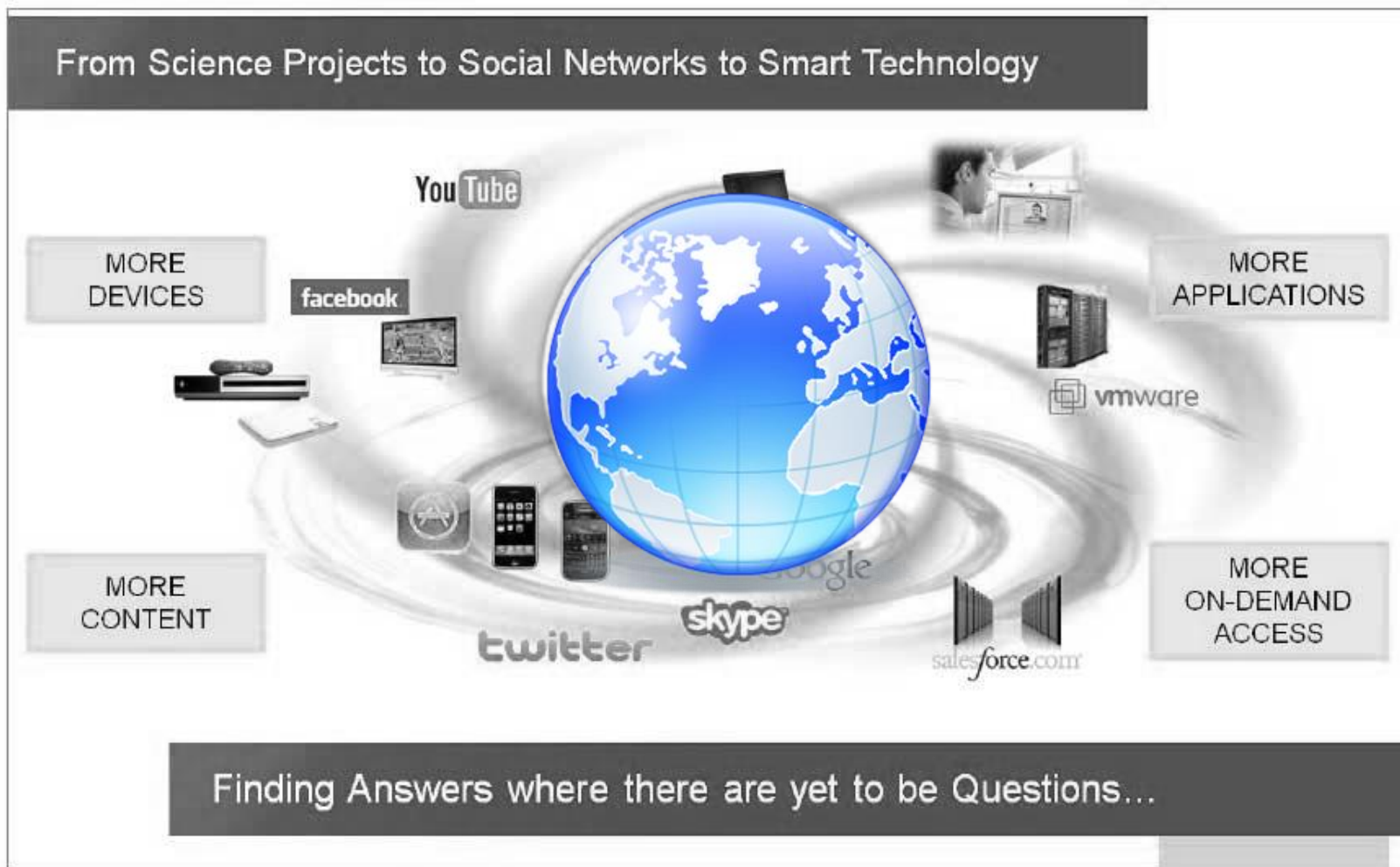
本日のテーマと目的

- 可視化は、計算機や計測装置等から生成される膨大な数値データから気付きを得るための基盤技術として重要になっている。本講義では、計算科学と密接な関係にある可視化技術の基礎と応用について説明する。

可視化：ビッグデータ時代の科学を拓く

可視化について

ビッグデータ時代の科学を支える素養



Source: IDC's Digital Universe Study, sponsored by EMC, June 2011

計算科学が拓く世

1.8 zeta bytes in 2011

データと情報

データ

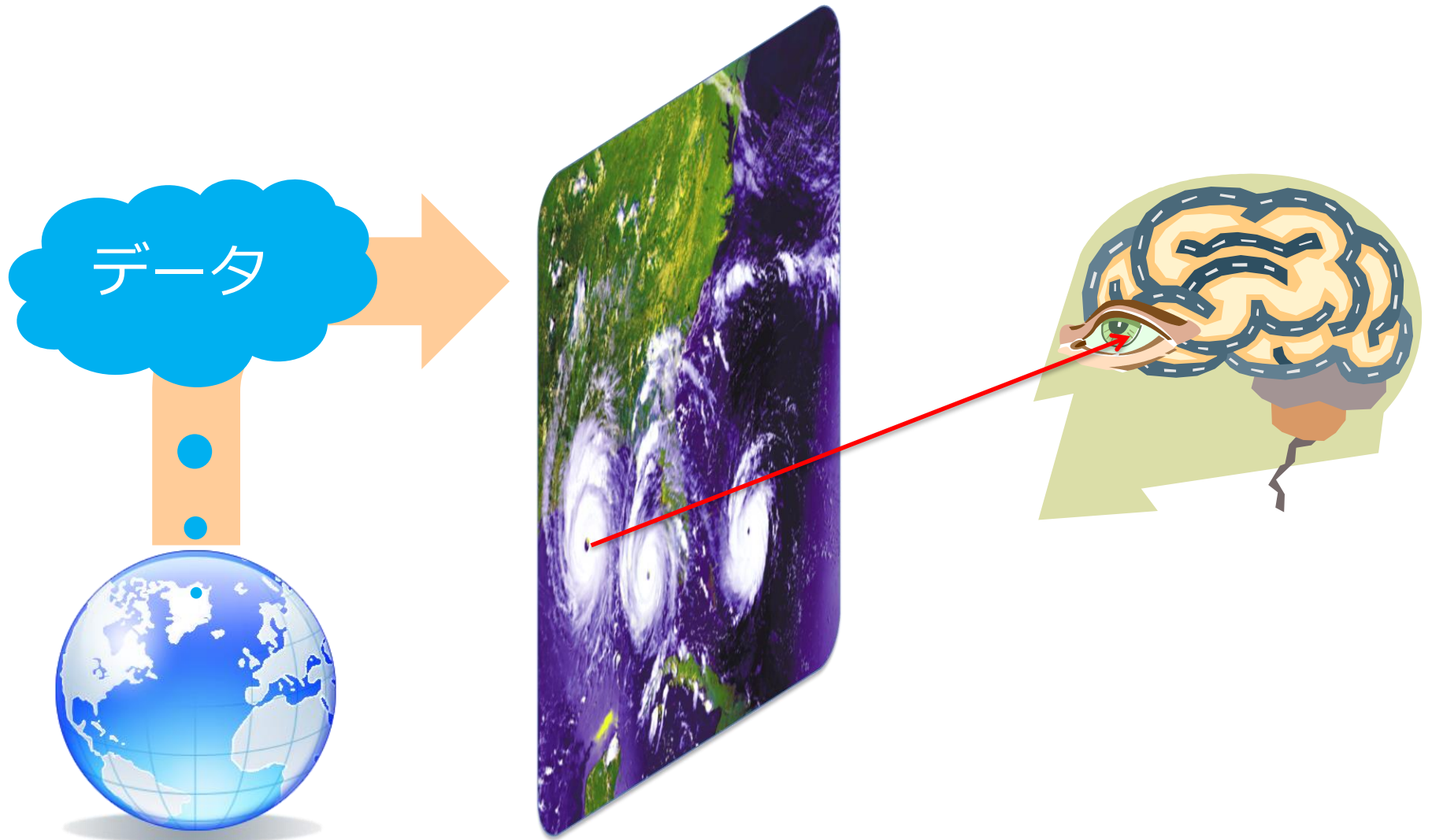
何かを符号で表現したもの

可視化

情報

人間が認識したデータ

可視化：データと脳をつなぐ



可視化研究と性能評価

医・理・工学

計測・計算

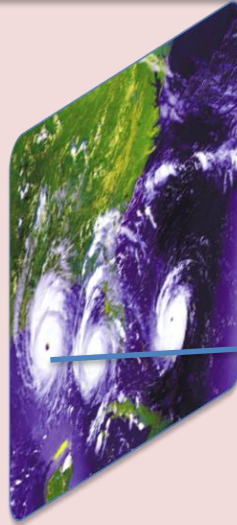
データ



どんな現象をデータ化
できたか？

情報科学

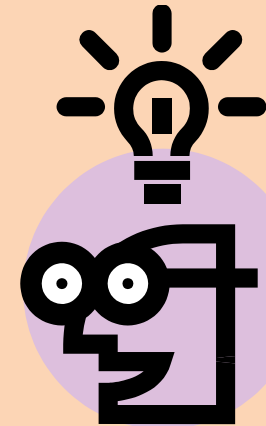
画像化



どれほど効率よく画像
化できたか？

認知科学

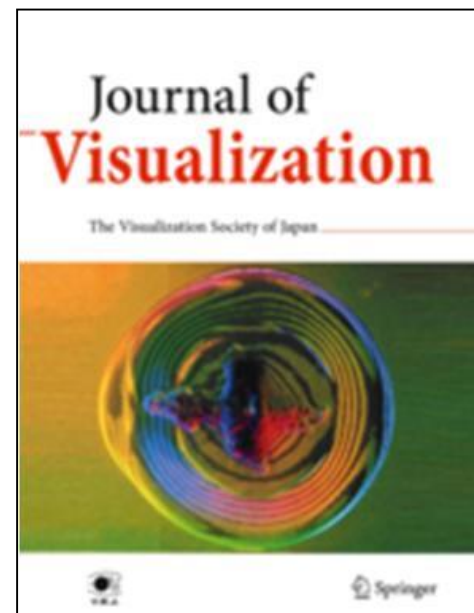
認識



どれほどの気づきを得
たか、どんな行動変容
に結び付いたか？

Journal of Visualization

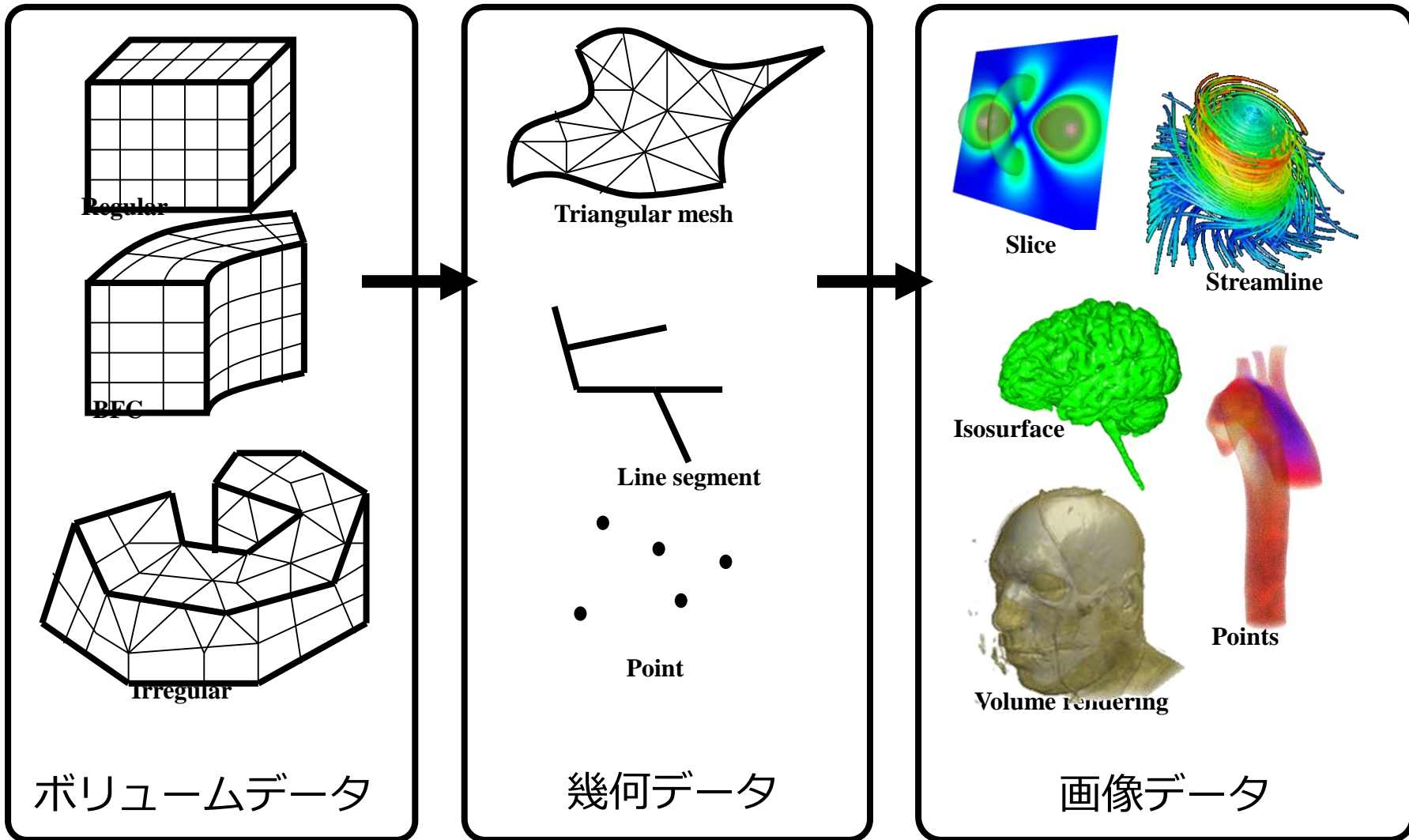
- History
 - Springer Vol.1(1998)-
- Editors-in-Chief:
 - K. Koyamada
 - K.C. Kim
- Scope
 - Visualization is an interdisciplinary imaging science devoted to making the invisible visible through the techniques of experimental visualization and computer-aided visualization.



データ可視化技術

Visual analytics ビジュアル分析

データ可視化パイプライン



可視化：ビッグデータ時代の科学を拓く

いろいろな可視化

計測データの可視化



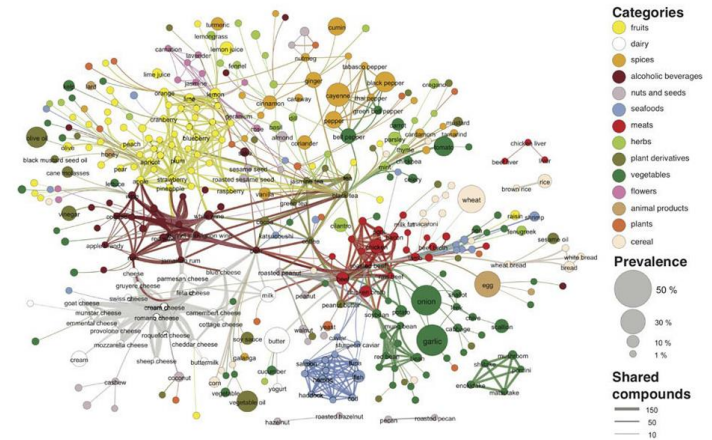
流れの可視化
(データ提供：Gustavo R.S. Assi)



船舩の可視化
(データ提供：田中先生@立命館大学)

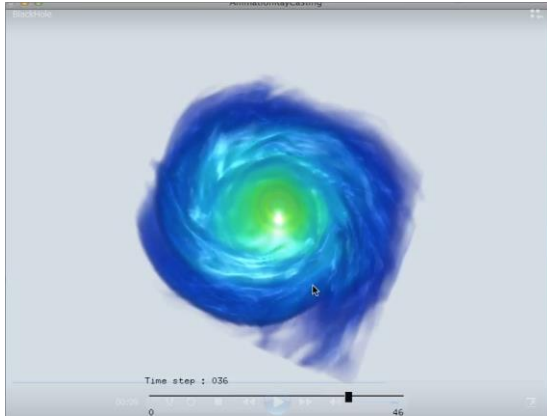


医療データの可視化
(データ提供：www.oagpubco.com)



Yong-Yeol Ahn, et. al,
Flavor network and the principles of food pairing, Nature

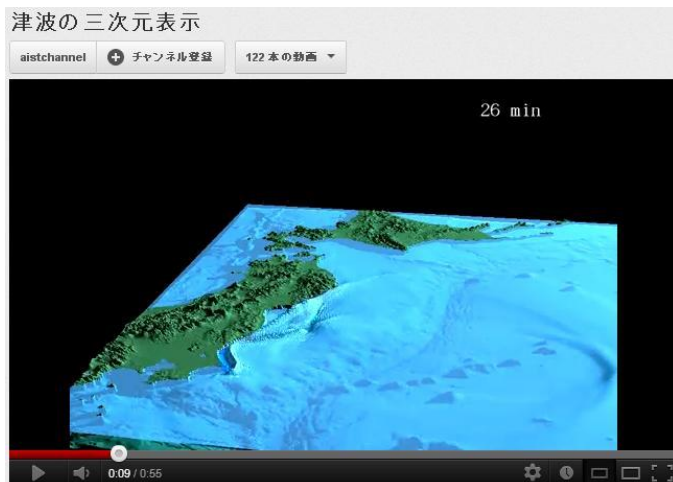
シミュレーション結果の可視化



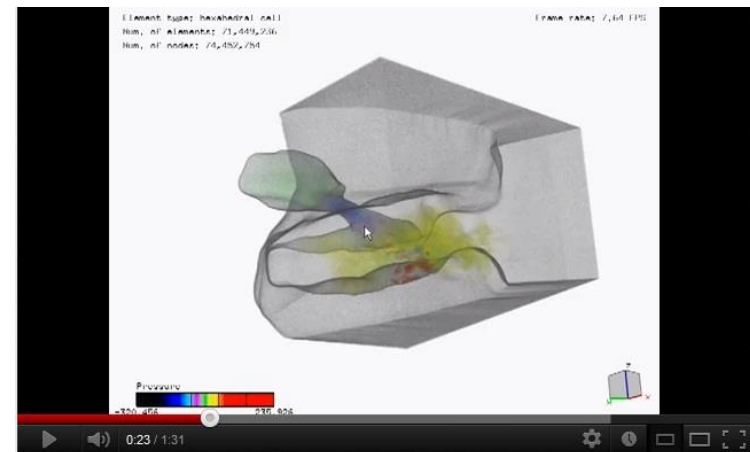
ブラックホールシミュレーション
(木内先生@京都大学)



自動車衝突解析(LOCTITE sitio Web www.loctite.com)

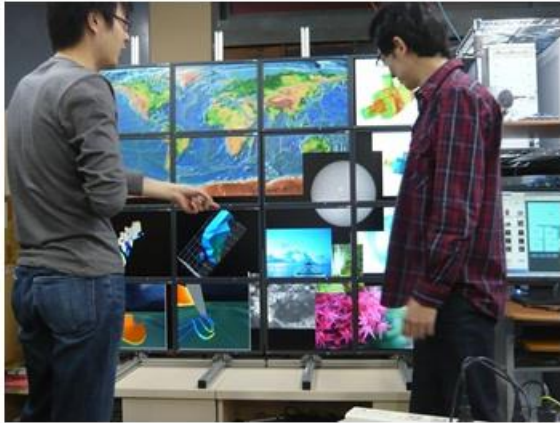


津波シミュレーション (産総研)



大規模口腔流体解析結果 (野崎先生@大阪大学)

大型表示装置を使った可視化



複数アプリケーションの表示例



星間物質の乱流シミュレーション結果
(村主先生@白眉プロジェクト)



立体映像提示 (アナグリフ方式)
(キッズサイエンススクール)



N体シミュレーション結果 (暗黒物質)
(矢作先生@京大メディアセンター)



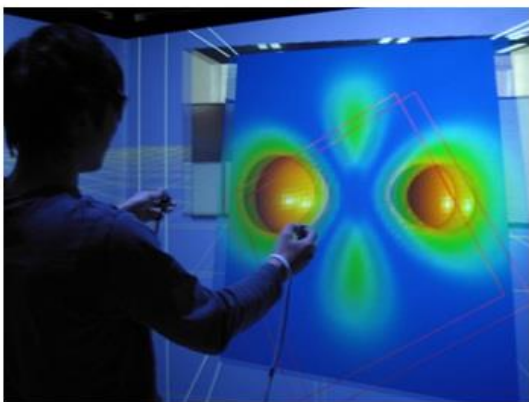
大規模ポンプの構造解析結果
(奥田先生@東京大学)



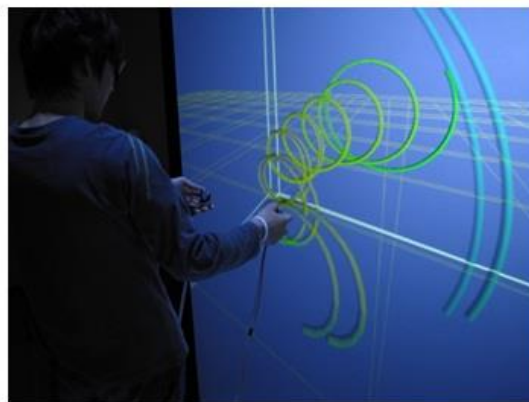
PC x 11
NIC: 1Gbps
LCD: 40

システム構成

没入表示装置を使った可視化



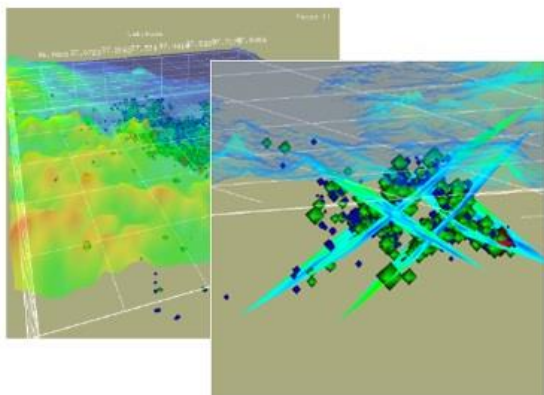
任意断面可視化



流線可視化



没入仮想空間提示



新潟中越地震の震源分布（断層面の推定）

（片尾先生@京大防災研）



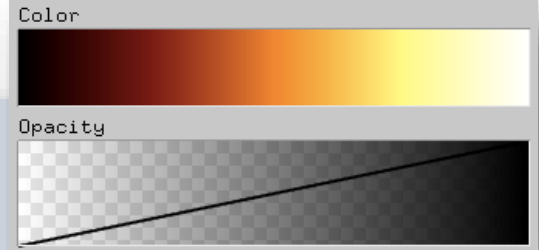
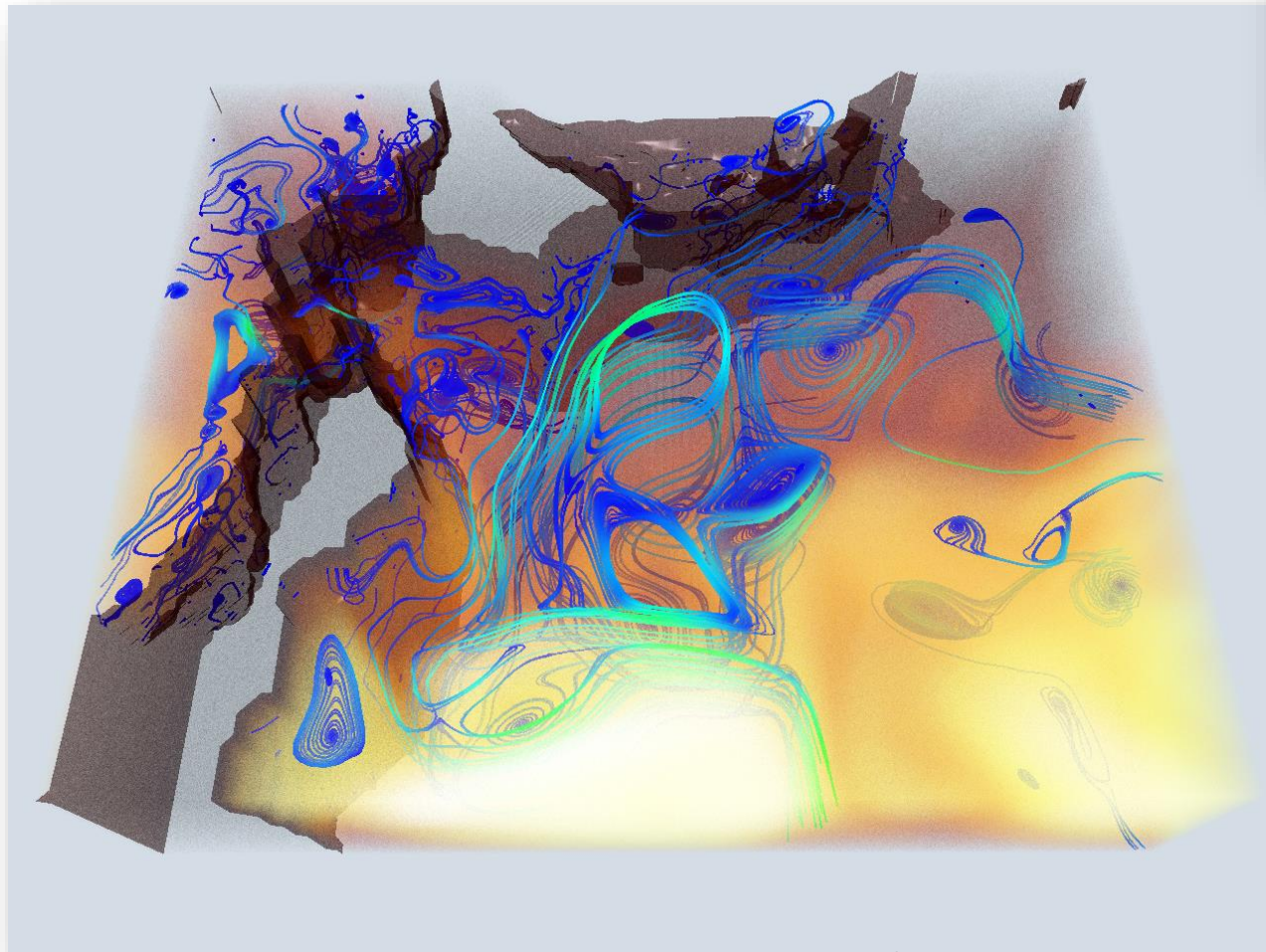
システム構成



- PC x 4
- 磁気装置
- 偏光メガネ
- 操作デバイス

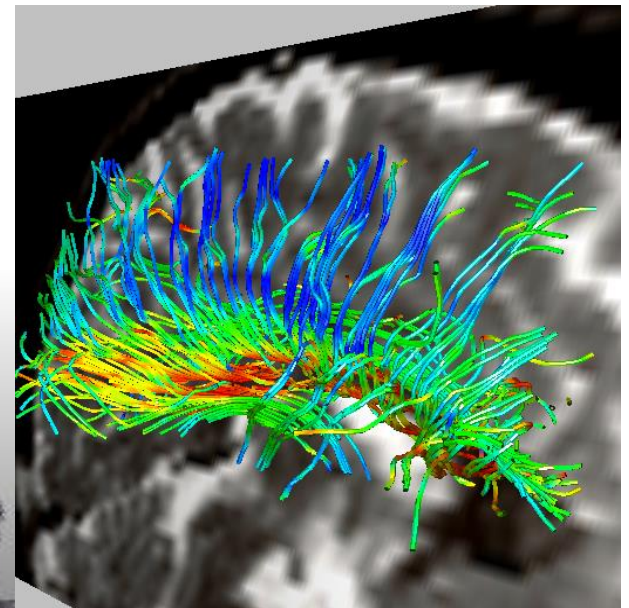
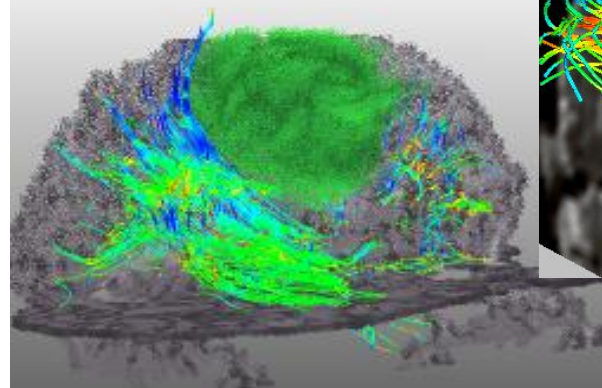
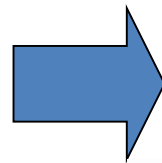
青森沖海流解析結果

(石川先生@京大)



脳白質神経線維可視化技術

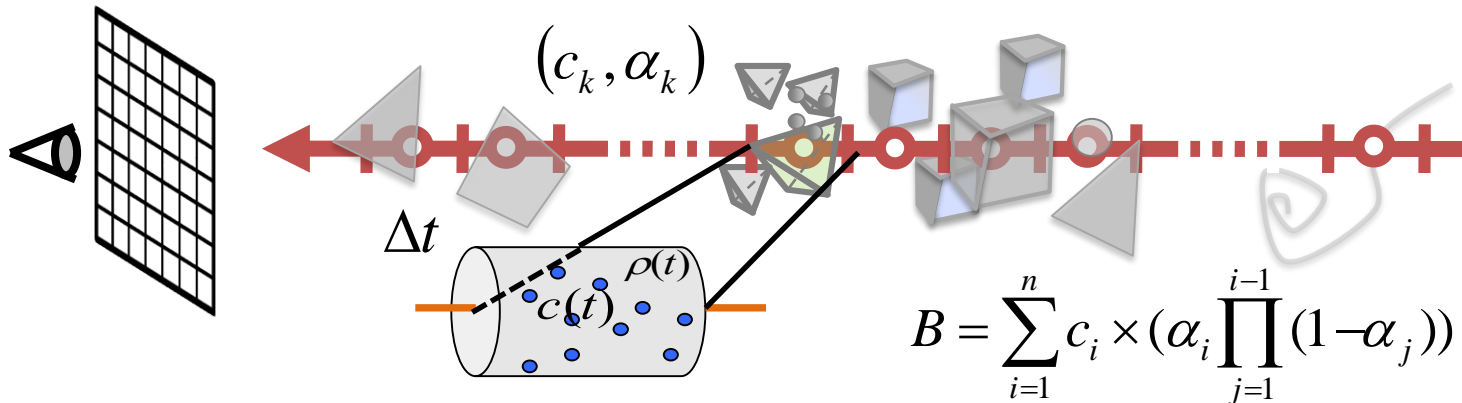
DT-MRIデータはテンソルデータの種類である。テンソルの最大固有値とその固有ベクトルから、神経線維の方向を計算し、流線可視化手法を適用することで、神経の流れを表現できる。



可視化：ビッグデータ時代の科学を拓く

可視化の拡張性

超拡張性の実現：粒子レンダリング



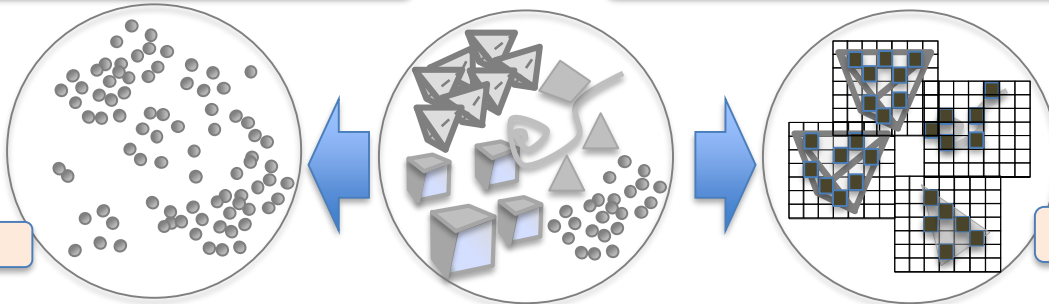
オブジェクト空間：不透明度から密度関数推定

イメージ空間：不透明度を確率として評価

$$\alpha(s) = 1 - e^{-\pi r^2 \rho \Delta t}$$

$$\rho(s) = -\frac{\log(1 - \alpha(s))}{\pi r^2 \Delta t}$$

粒子密度関数を導出

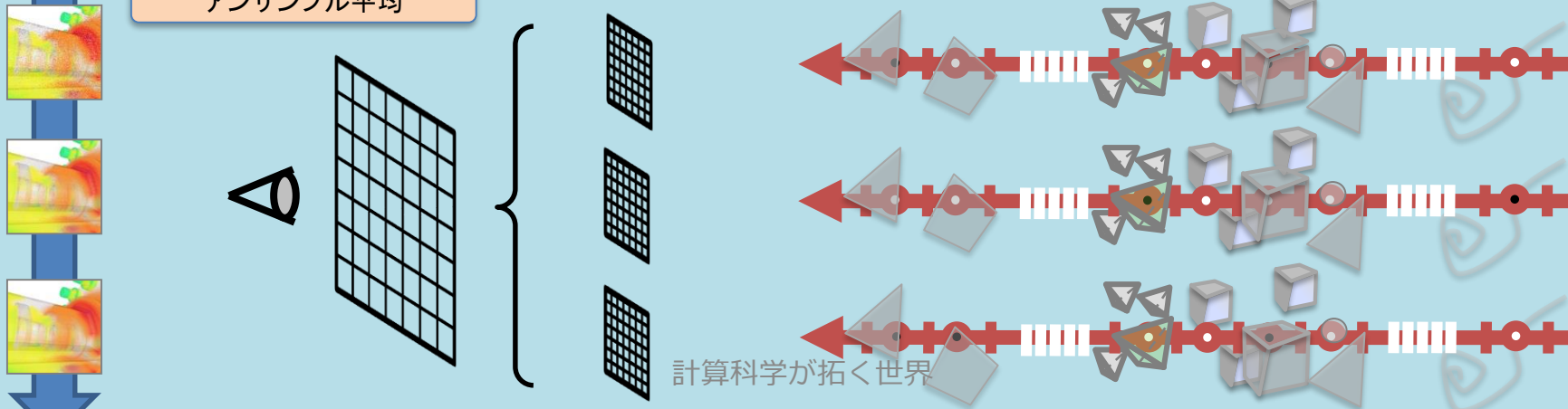


$$B = \sum_{k=1}^n c_k P_k$$

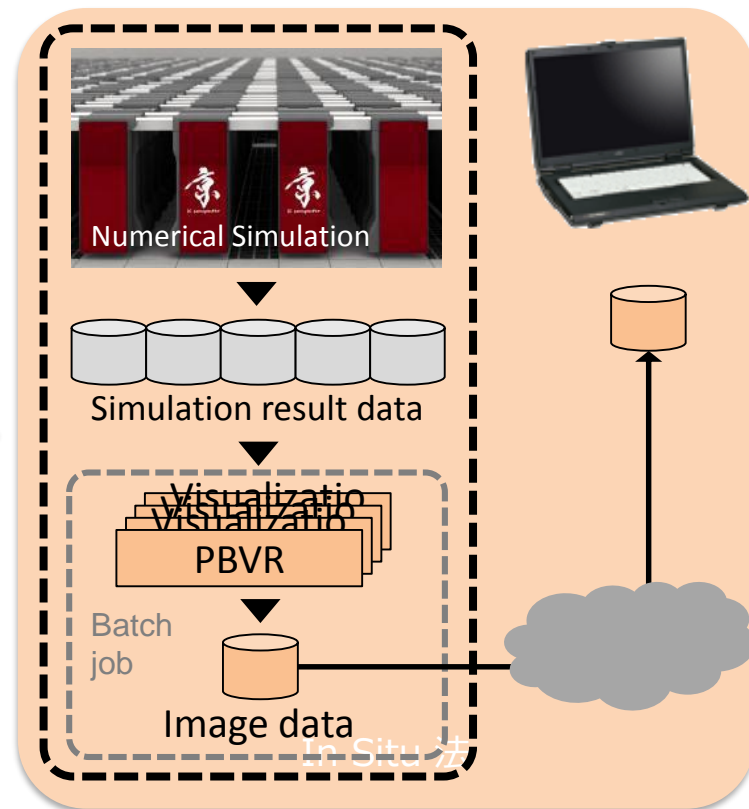
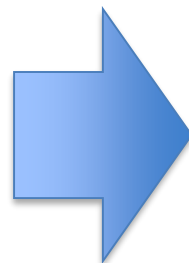
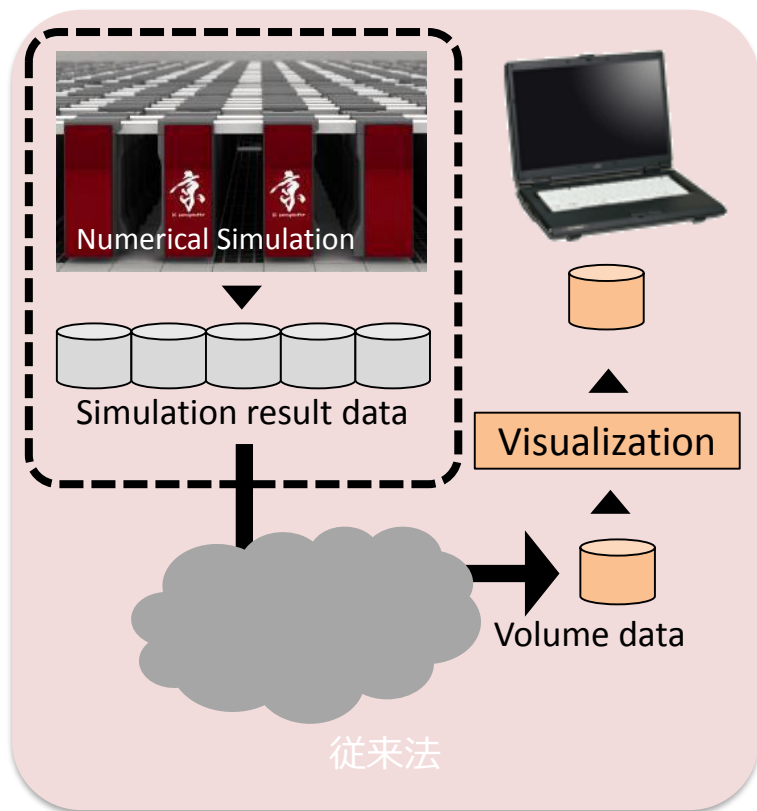
$$P_k = \alpha_k \prod_{j=1}^{k-1} (1 - \alpha_j)$$

粒子発光が輝度値となる確率

アンサンブル平均



In-situ Visualization on K computer



経過時間：1時間以上

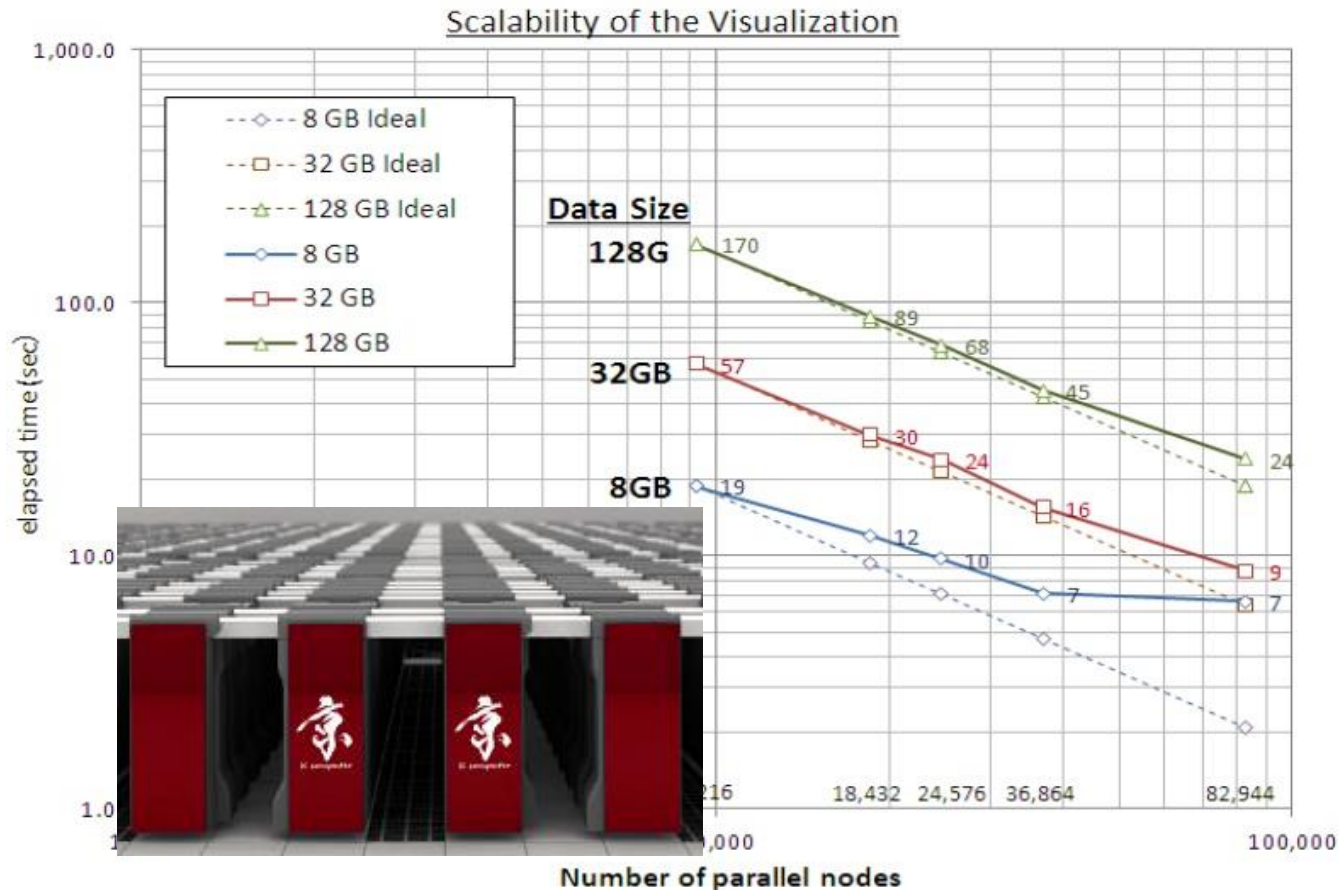


経過時間：10秒程度

Ogasa et al., "Visualization technology for the K computer", Fujitsu Scientific & Technical Journal, Vol.48, No.3, 2012.

計算科学が拓く世界

Visualization in K-computer system



Ogasa, A; Maesaka, H; Sakamoto, K; Otagiri, S, "Visualization Technology for the K computer,"
Fujitsu Sci. Tech. Journal, Vol.38 No.4, 2012

タイルド表示装置

Tiled Display Wall (TDW)



可視化：ビッグデータ時代の科学を拓く

科学的可視化

子供の科学

原田三夫, “この雑誌の役目”, 1924年10月号

・・・しかしこの雑誌の一番大切な目的は、ほんとうの**科学**というものが、どういうものであるかを、皆さんに知っていただくことであります。ちかごろは「**科学科学**」とやかましくいいますが、ほんとうに**科学**というものを知っている人はたくさんないようです。人は生まれながら美しいものを好む心を持っていますが、それと同じように自然の物事について詳しく知り、深くきわめようとする欲があります。昔からその欲の強い人が調べた結果自然の物事の間には、たくさんの定まった規則のあることがわかりました。**科学**ということは、この規則を明らかにすることです。多くの人が**科学**と言っているのは、たいていはその応用にすぎません。この規則を知ることによって人間は自然にしたがって無理のないように生き、楽しく暮らすことができ、これを応用して世が文明におもむくのです。

科学とは、物事の間因果関係を明らかにすること



科学する心

小林秀雄, “科学する心”, 岩波書店講演集CD, 1970年

・・・それは、まあこの環境を知る一種の**科学**論だなあ。**科学**論てものはねえ、とてももう面倒なものなんです。で、ただ、科学ってものはだなあ、ものがその、ものをこの本当にものをするのが**科学**ではない。あれはものの法則を知るんです。いいですか、そこはねえ、あのよおく考え貰わないといけないんだよ。つまりだなあ、えー、**科学**ってものはいつでも法則をめぐっているんです。ほんとに僕らの経験ってものを、ほんとの生きる経験ってものは**科学**はいらないんです。生きていなくてもいいんです。生きている人間ってものは、科学は、そんなものは認めないんです。いつでも、**科学**はねえ、その、規則をめぐけるんです。ものともものはどういう関係にあるかってことを、因果関係だね、一口に言えば因果関係ってものは、自然はどういうふうに動いているかって、いうその因果関係っていうものを目指しているんです・・・



科学は因果関係を目指す

科学教育

biology letters
 14 October 2011, 7, 168–172
 doi:10.1098/rsbl.2011.0100
 Published online 25 December 2010

Blackawton bees

R. S. Blackawton¹, S. Akpan², A. Allen³, S. Baker⁴, A. Barrows¹, C. Blair¹, M. Chourah¹, J. Cohen¹, N. F. J. Cunniff¹, L. Fraquelli¹, C. Hackhoff¹, A. Hinton-Milner¹, M. Hutchings¹, B. Inghs¹, D. Janssen¹, A. Littlejohns¹, G. M. Littlejohns¹, M. Lott¹, J. Mackenzie¹, A. O'Neil¹, N. Richards¹, J. Robinson¹, J. Springett¹, A. Wainwright¹, T. Richards-Lynn¹, D. Richards¹ and R. B. Lott^{1,2*}

¹Blackawton Nature Study, Blackawton, Devon, UK; ²Department of Biology, University of Exeter, Exeter, UK; ³Department of Biology, University of Exeter, Exeter, UK; ⁴Department of Biology, University of Exeter, Exeter, UK

Background: Real science has the potential to not only amuse, but also transform the way one thinks of the world and oneself. This is because the process of science is little different from the deeply resonant, natural processes of play. Play involves humans and other animals in discrete (and often) rule-based situations and patterns. When one adds rules to play, a game is created. This is science: the process of playing with rules that enables one to reveal previously unseen patterns of phenomena that extend our collective understanding of nature and human nature. When thought of in this way, science education becomes a more enlightening and instructive process of asking questions and devising games to address those questions. Here, because the outcomes of all games-playing is unpredictable, supporting this 'messiness', which is the engine of science, is critical to good science education (and indeed creative education generally). Indeed, we have learned that doing 'real' science in public places can, against all odds, transform an individual and adults in understanding the processes by which we make sense of the world. The present study (on the vision of bumblebees) goes even further, since it was not only performed outside our laboratory (in a village church in the southwest of England), but the 'games' were themselves devised in collaboration with 21 5- to 10-year-old children. They asked the questions, hypothesized the answers, designed the games (in other words, the experiments) to test their hypotheses and analysed the data. They also drew the figures (in coloured pencil) and wrote the paper. Their headteacher (Dave Strudwick) and I devised the experimental protocol, but children's 'real' science was the bees and transformed the children's science text (which was done with smaller groups of children at the school's local village hall) into what follows in a novel study (scientifically and conceptually) to past literature, which is a challenge. Although the historical context of any study is of course important, including references in this instance would be inappropriate for two reasons. First, given the way scientific data are naturally reported, the relevant information is simply

inaccessible to the literate ability of 5- to 10-year-old children and second, the motivation for any scientific study (at least one of interest) is not one's own observations of the world; the children was not inspired by the scientific literature, but their own observations of the world. This lack of historical, scientific context does not diminish the resulting data, scientific methodology or merit of the discovery for the scientific and 'non-scientific' audience. On the contrary, it reveals science in the truest (most authentic) form, and in this way makes explicit the commonality between science, art and indeed community activities.

Principal findings: We discovered that bumblebees can use a combination of colour and spatial relationships to identify which colour of flower to forage from. We also discovered that science is cool and fun because you get to do stuff that no one has ever done before. (Children from Blackawton)

Keywords: *Bombus agrorum*, half-tandem bumblebee; visual perception; colour vision; behaviour

1. INTRODUCTION

(A) Once upon a time...

People think that humans are the smartest of animals, and most people do not think about other animals as being smart, or at least think that they are not as smart as humans. Knowing that other animals are as smart as us means we can appreciate them more, which could also help to help them.

Scientists do experiments on monkeys, because they are similar to man, but bees could actually be closer to man too. We see bees in the natural habitat doing what they do, but we do not really see them doing things (such as solving human puzzles like Sudoku). So it makes very sense if they could solve a human puzzle. If they could solve it, it would mean that they are really very smart (that we thought before), in which would mean that humans might have some link with bees. If we are as like as we are now, then understanding them could help us understand ourselves better.

To get ready to do the experiments with the bees we first talked about science being about playing games and making puzzles. We then got some games and made up games to play using random points of physical education equipment. This gave us experience of thinking of games and puzzles. After talking about what our games to other people (after explaining what it is like to create games and what some rules are), we talked about seeing the world in different ways by wearing big eyes, mirrors and hold-up books. We then watched the David Letterman video of 'Rugby Dog Trials', in which dogs were trained to do funny things, but we see how we had to learn to play a puzzle that three (a neutered) and Mr Strudwick (our headteacher) gave us (which took an artificial hour 10 000 trials to solve, but only four for us). Afterwards, we started asking questions about bees, and then more specific questions about seeing colour with the bee sense (figure 1).

We came up with lots of questions, but the one we decided to look at was whether bees could learn to

Colour and spatial relationships in bees R. S. Blackawton et al. 171

Figure 3. Confirmed and responses to test 1. (a) The pattern of colours that the bees were tested on in their third test (see text for explanation). (b) A table showing the preferences of each bee during test 1 (see text for explanation).

	COLOURED	MIX COLOURED
1	1	1
2	1	1
3	1	1
4	1	1
5	1	1
6	1	1
7	1	1
8	1	1
9	1	1
10	1	1
11	1	1
12	1	1
13	1	1
14	1	1
15	1	1
16	1	1
17	1	1
18	1	1
19	1	1
20	1	1
21	1	1
22	1	1
23	1	1
24	1	1
25	1	1
26	1	1
27	1	1
28	1	1
29	1	1
30	1	1
31	1	1
32	1	1
33	1	1
34	1	1
35	1	1
36	1	1
37	1	1
38	1	1
39	1	1
40	1	1
41	1	1
42	1	1
43	1	1
44	1	1
45	1	1
46	1	1
47	1	1
48	1	1
49	1	1
50	1	1
51	1	1
52	1	1
53	1	1
54	1	1
55	1	1
56	1	1
57	1	1
58	1	1
59	1	1
60	1	1

Figure 2b. Shows a table of the choices made by the bees during this test. In total, the bees went to the green middle flowers only 34 times, and to the outside blue and yellow flowers 76 times (see text in figure 2b). So, out of 110 attempted forages, 30.9 per cent went to the middle flowers. If the bees were generally going to the middle flowers, 30 per cent of the time, which is very close to 30 per cent. We conclude that the bees did not solve test 1 by only going to the middle flowers of each question (which is probably the case). However, two of the bees (labelled B/O and B) went more often to the green, middle flowers. So they seemed to have learned a different rule to the other three bees.

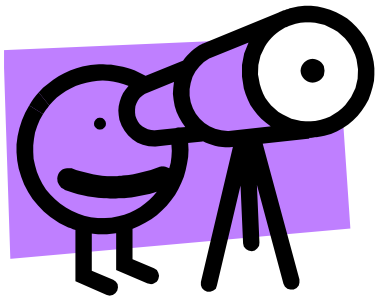
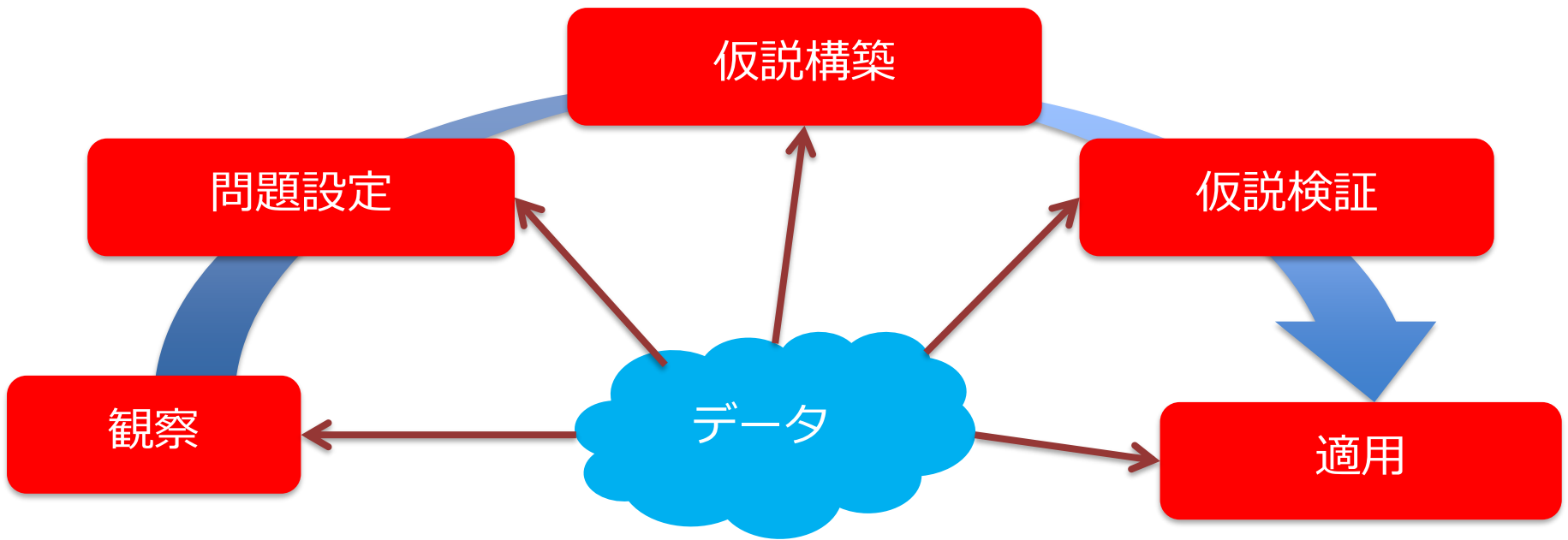
(c) Test 3 (the second experiment).

In the third test, instead of having large squares of yellow and blue around the outside of each panel, and a smaller square of yellow and blue on the inside of each panel, we took the four inside flowers and put them in the corners of each panel. See figure 1 for a hand drawing of what this test looked like. We did this because we wanted to see if the bees solved test 1 by learning during training to go to the colours of each panel that were flowers in number. We could also see if they still preferred to go only to the middle

Elementary school students, "Blackawton bees," Biology Letters (2011) 7, 168–172

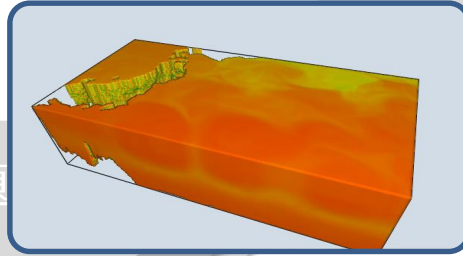
- USやEUでは、小学校で科学的方法が教育されている
- 日本では、大学や大学院で卒論や修論を通じて暗黙的に伝えられる
- 日本では科目試験（正解がひとつ）に極端にこだわる
- ほとんどの日本人学生は科学的方法をキチンと学ばない

科学的方法の流れ



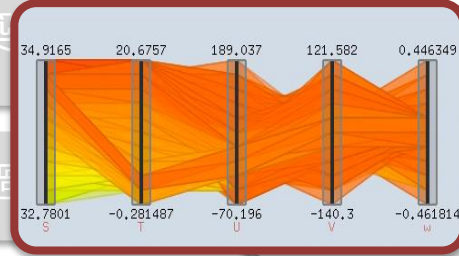
海洋科学における可視化

問題



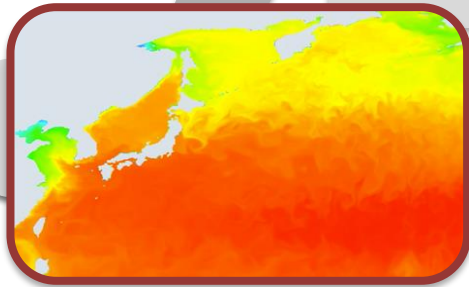
仮説構築

拡大&濾過

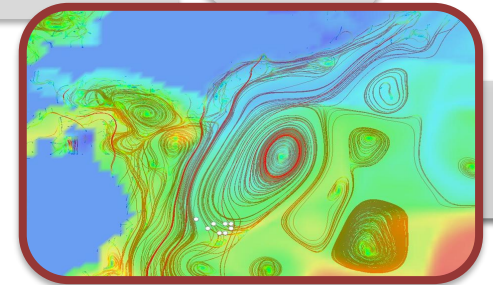


検証

俯瞰



対話的詳細化



データ



計算科学が拓く世界

可視化：ビッグデータ時代の科学を拓く

科学と因果発見技術

仮説



- ふたつの変数間のある方向をもった仮の関係
- その関係は、観測データによって検証される
- 「もしXならばY」のような因果関係によって記述される

因果関係発見は、科学における本質である

因果発見技術

M. Chen, et al., "From data analysis and visualization to causality discovery," IEEE Computer , 44(10):84-87,

四つの挑戦


- 因果推論を促進するためのインフラ整備
- 可視化活用能力の飛躍的向上
- 継続的なデータ洪水の対話的処理における負荷の軽減
- 推論過程における不確からしさの評価・可視化に対する要求への対応

INVISIBLE COMPUTING

From Data Analysis and Visualization to Causality Discovery

Min Chen, Anne Trefethen, René Bañares-Alcántara, Marina Jirotko, and Bob Coecke
University of Oxford, UK

Thomas Ertl and Albrecht Schmidt
University of Stuttgart, Germany



As data becomes invisible, emerging technologies can help human analysts and decision makers understand, model, and visualize causal relationships.

Nowadays the public, and even most decision makers, rarely see raw data. People are used to statistical results and visualized data presented by scientists, data analysts, or news readers. As computers disappear into the background, raw data is also becoming invisible.

The reliance on data analysis and visualization to improve the usability of information and communications technology echoes Mark Weiser's vision of ubiquitous computing: "... only when things disappear in this way are we freed to use them without thinking and so to focus beyond

CAUSALITY REASONING

Causality is the fabric of our dynamic world. We all frequently attempt to reason about the causes of everyday events—for example, why do I have a headache, or what has upset Alice?—in order to better manage them. We also seek to understand the origins of numerous complex phenomena such as social divisions, economic crises, global warming, and terrorism. Some of the greatest scientific discoveries, from Newton's laws of motion to Darwin's theory of natural selection, involve causality.

Causality has been studied in

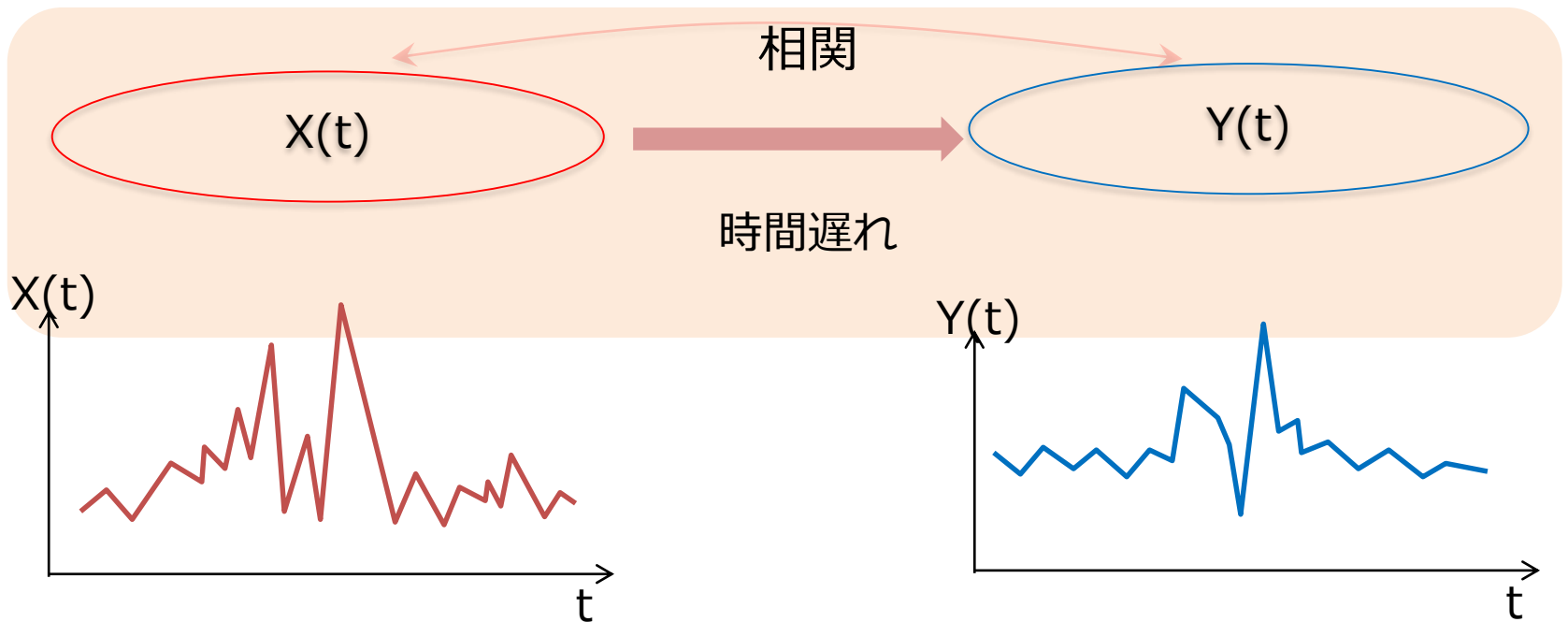
(Natural Philosophy of Cause and Chance, 1949).

Figure 1 illustrates Born's four levels of causality reasoning and the transitions between them. *Probabilistic causation* is a form of preliminary reasoning based on statistical correlation. "Overwhelming evidence" abstracts probabilistic causation to *logical causation*. When there is a scientific understanding of causality, *quantitative laws* of nature describe the functional relationship between measurable attributes of various events. According to Born, quantum mechanics offers the *fundamental understanding* of causation in physics.

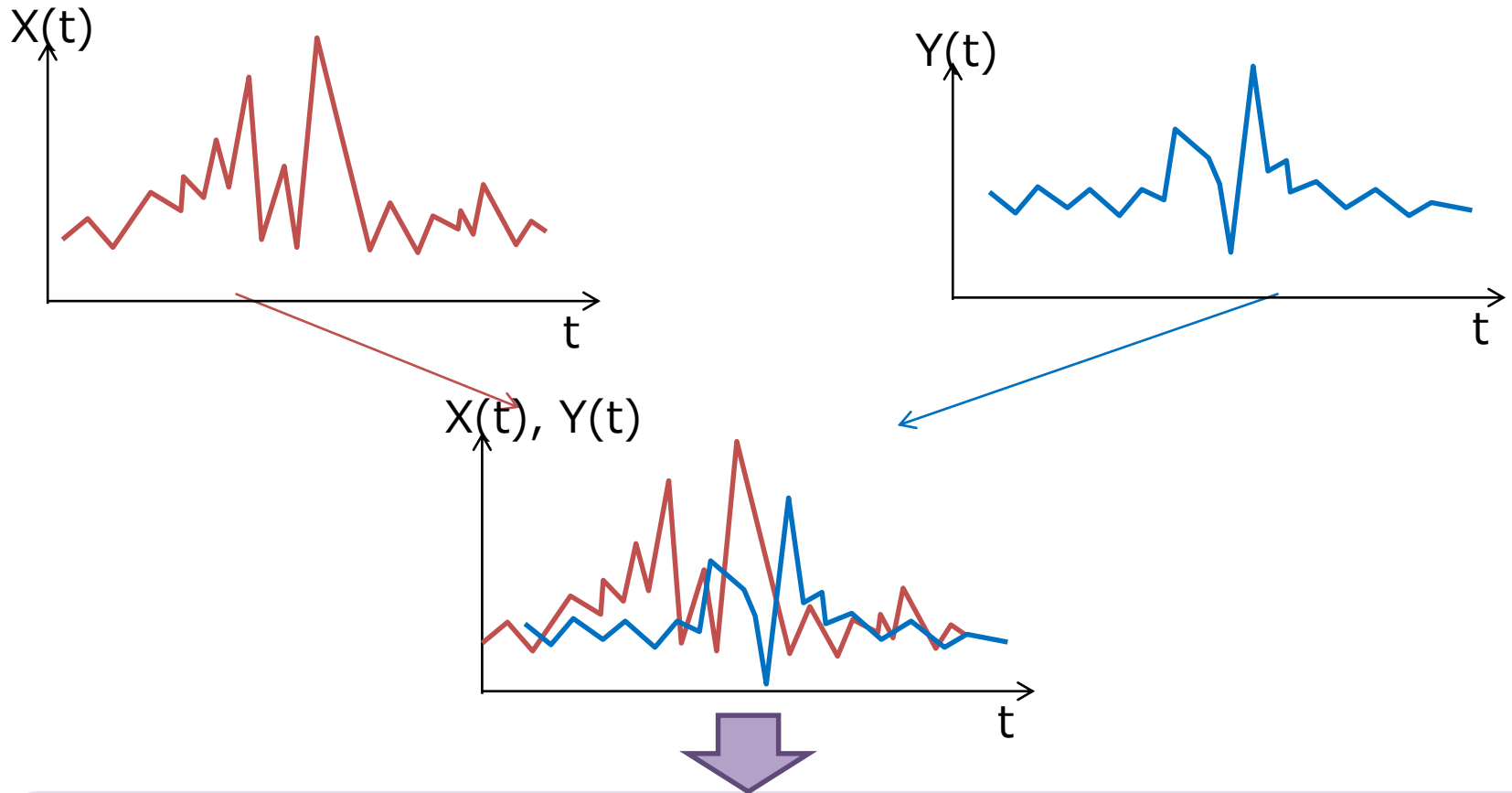
よりよい理解に向けて

時系列データ向け因果発見

- 因果関係は、あるプロセスともう一つのプロセスとの間の関係を表す
- 最初のプロセスは、二番目のプロセスに対して、部分的に関与する。
- 統一された定義はないものの、さまざまな因果発見技術が報告され、実際に活用されている。



因果発見のための統計的検証法

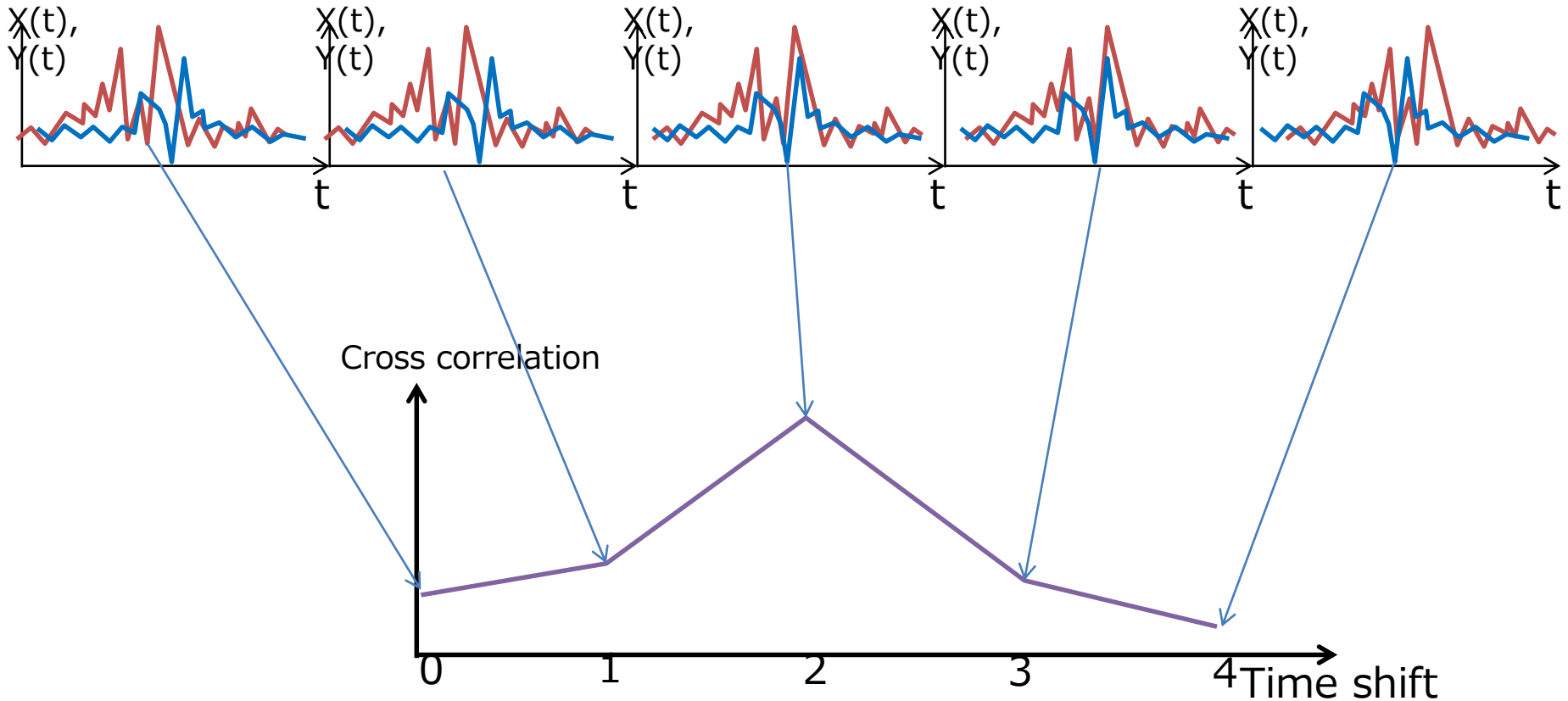


- 相互相関
- グレンジャー因果
- 収束的交差写像

因果確率

相互相関

time shift = 0 time shift = 1 time shift = 2 time shift = 3 time shift = 4



グレンジャー因果(GC : Granger Causality)

Granger, C. W. J. "Investigating Causal Relations by Econometric Models and Cross-spectral Methods". *Econometrica* 37 (3): 424–438 (1969)

It is a statistical test for a cause-and-effect relationship between two time series variables

We perform two vector auto-regressions as follows:

$$Y(t) = \sum_{l=1}^L a_l Y(t-l) + \epsilon_1 \quad (1)$$

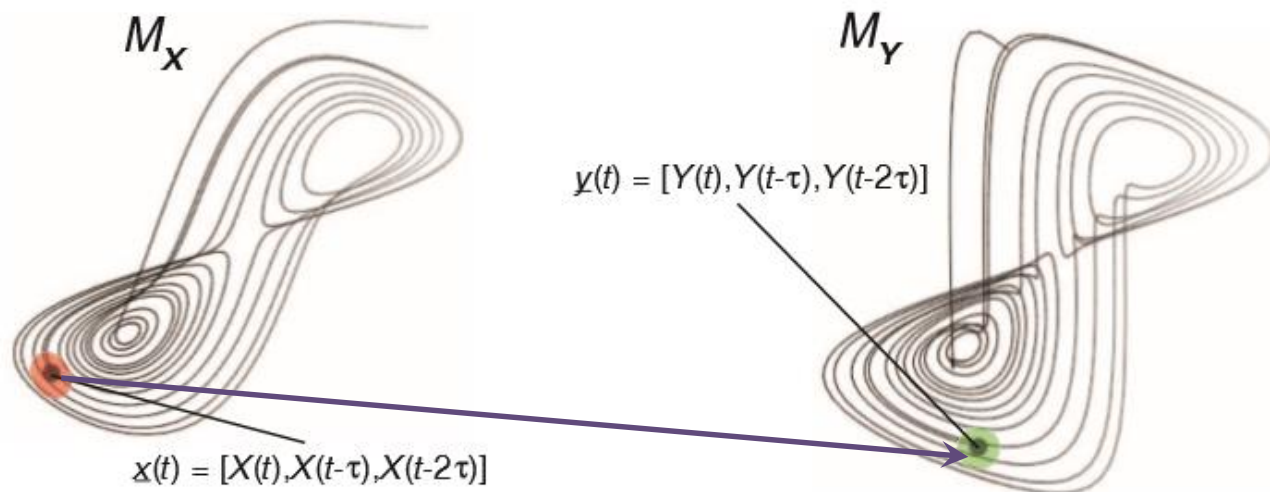
$$Y(t) = \sum_{l=1}^L a'_l Y(t-l) + \sum_{l=1}^L b'_l X(t-l) + \epsilon_2, \quad (2)$$

where L is the maximal time lag. We say X causes Y if eq (2) is statistically significantly better than eq (1).

収束的交差写像(CCM: Convergent Cross Mapping)

Sugihara, George; et al., "Detecting Causality in Complex Ecosystems," Science 338 (6106) pp. 496–500 (2012)

- It is a statistical test for a cause-and-effect relationship between two time series variables
- It constructs two shadow manifolds, M_X and M_Y using lagged-coordinate embedding X and Y , respectively
- If X forces Y uni-directionally, variable Y will contain information about X , but not vice versa.

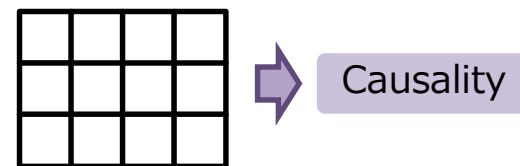


GC と CCM 使い分け

- どちらも相関は必ずしも因果を意味しないという問題を解決しようとする
- GCは、二つの変数の影響がお互いに独立で分離可能であるような確率的システムに適する
- CCMは、動的システム理論に基づき、二つの変数が相乗効果をもつようなシステムに適する

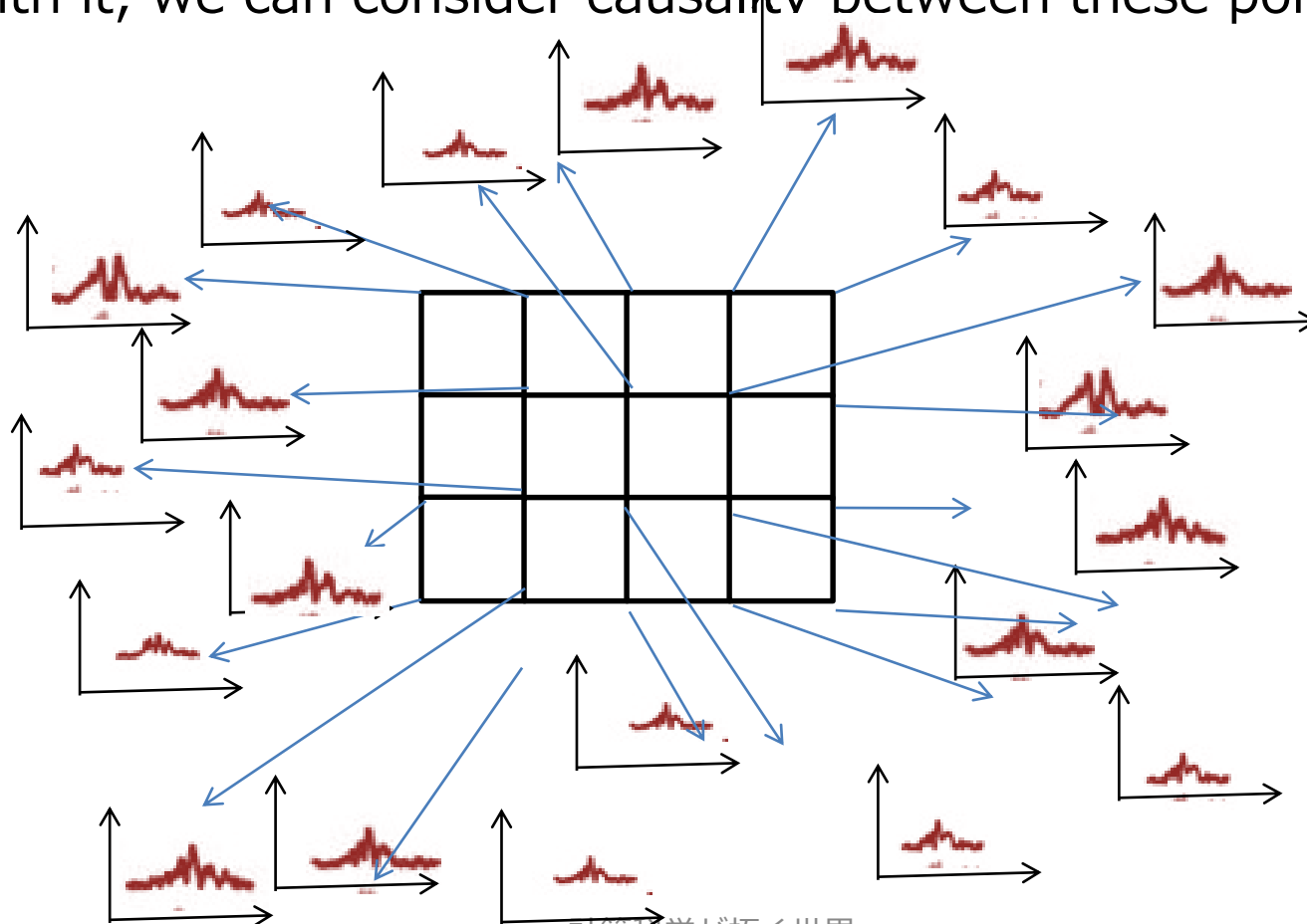
可視化：ビッグデータ時代の科学を拓く

時系列ボリュームデータにおける因果関係

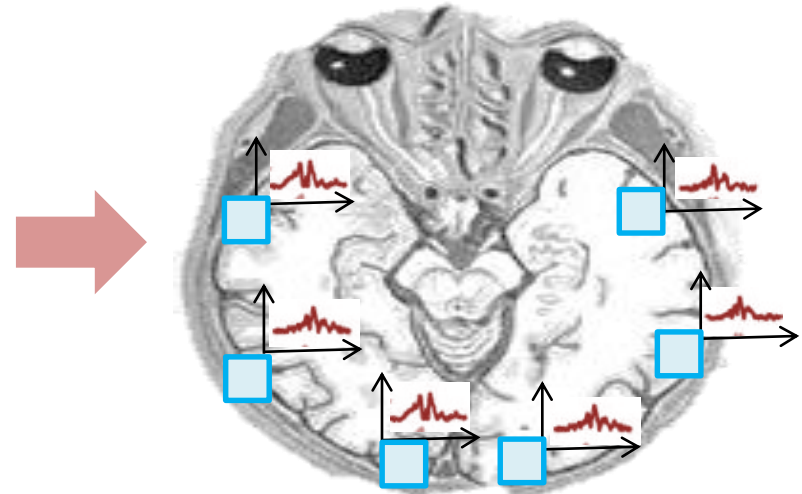


単一変数の時系列ボリュームデータ

- It defines univariate time series data defined at each grid point
- With it, we can consider causality between these points



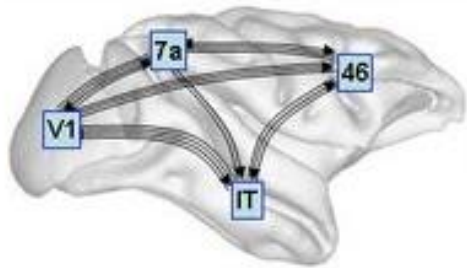
脳磁図(MEG: Magnetoencephalography)



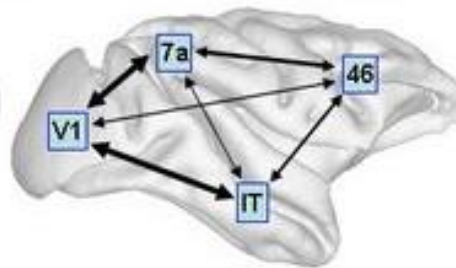
- It records magnetic fields produced by electrical currents occurring naturally in the brain, using very sensitive magnetometers.
- Its applications include basic research into perceptual and cognitive brain processes, localizing regions affected by pathology before surgical removal, determining the function of various parts of the brain, and neurofeedback.

結合解析

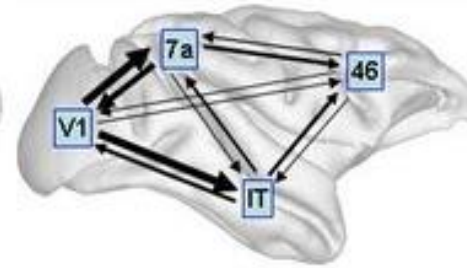
structural connectivity



functional connectivity



effective connectivity

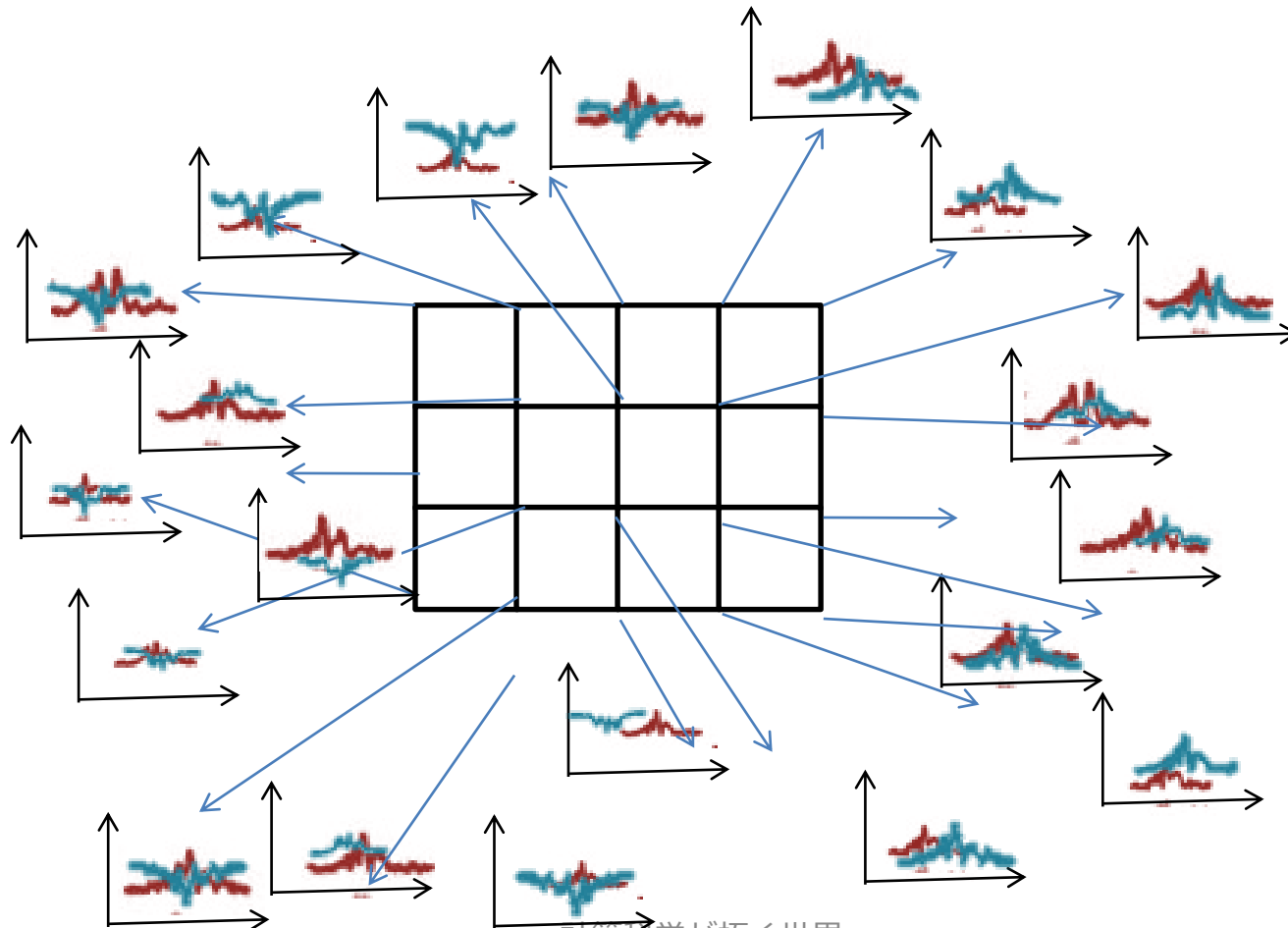


O. Sporns 2007, *Scholarpedia*

- Evaluation of structural connectivity (anatomical) using MR-DTI and Fiber-Tracking
- Confirmation of functional connectivity between activated areas using correlation
- Analysis of effective connectivity in neuronal groups using causation

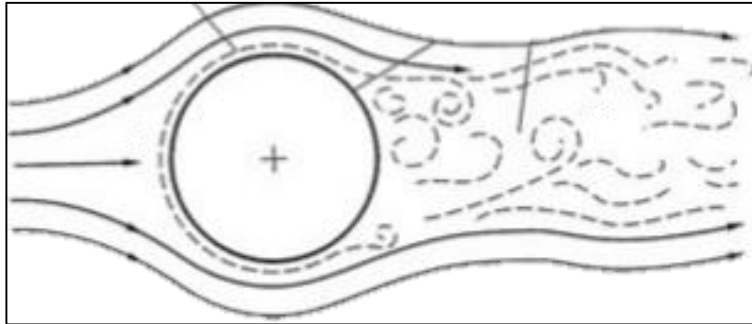
二変数の時系列ボリュームデータ

- It defines bivariate time series data defined at each grid point
- With it, we can consider causality at the point

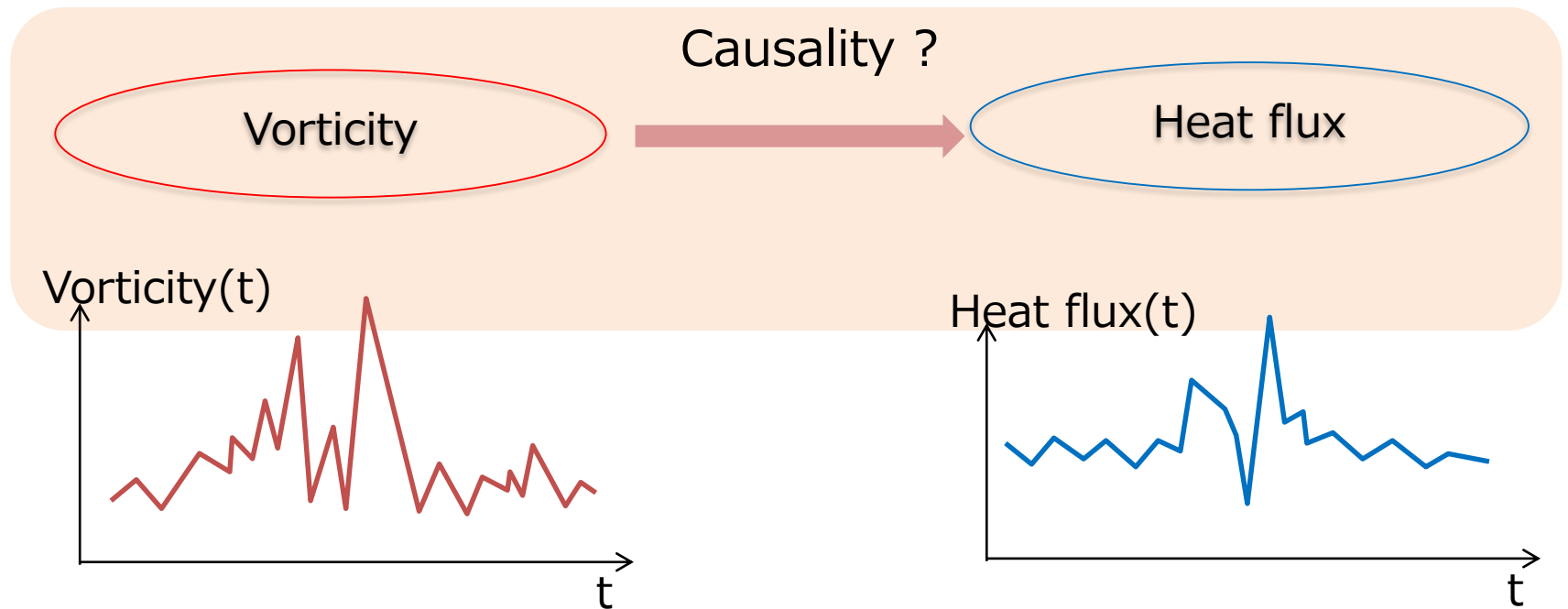


洗濯効果

K. Suzuki, "UNSTEADY HEAT TRANSFER IN A CHANNEL OBSTRUCTED BY AN IMMERSED BODY", 1994



The vortex flow contributes to the enhancement of the heat transfer

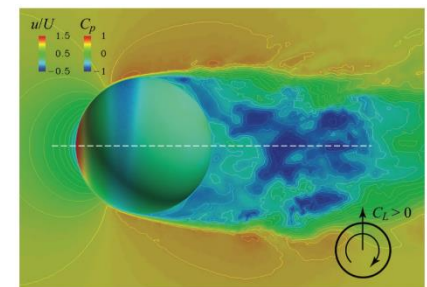
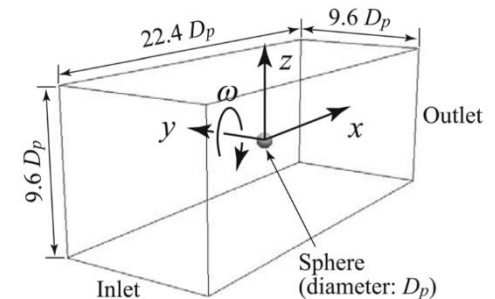


熱球周りの流体解析

Confirmation of the washing effect in the separated flow in the wake behind a sphere

- Model description

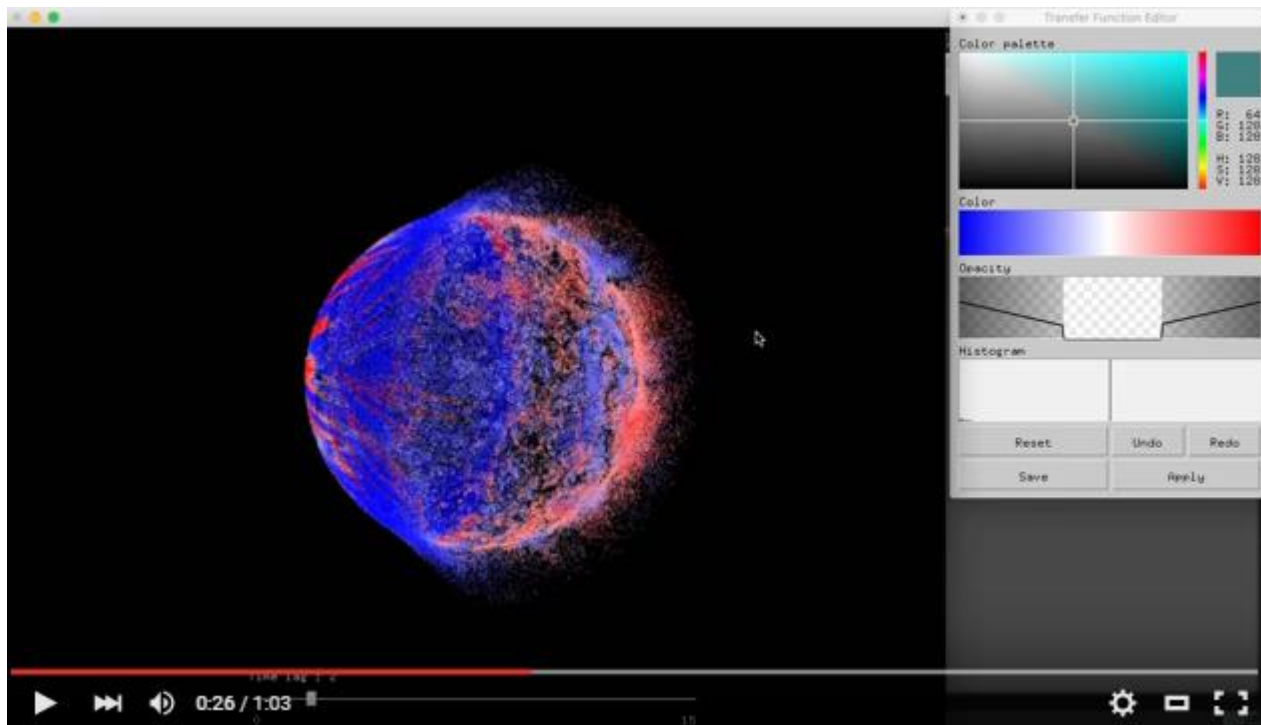
- Number of nodes : 15,321,546
- Number of cells : 18,917,887 (prism)
27,545,304 (tet)
- Number of time steps : 198
- File size : 3.5GB per step



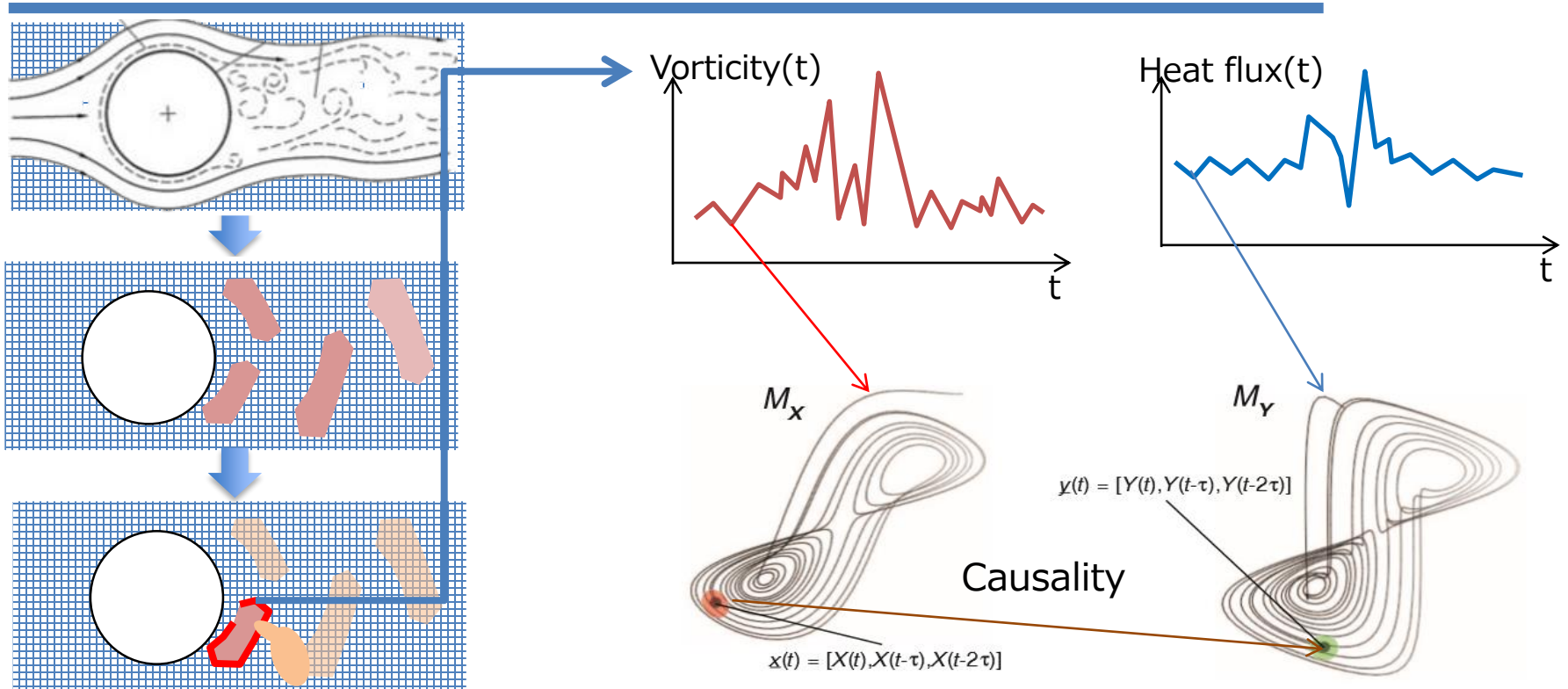
Negative Magnus lift on a rotating sphere at around the critical Reynolds number
Muto, Tsubokura, Oshima, Physics of Fluids, 24, 014102 (2012)

因果関係ボリュームデータ

- Calculation of cross correlation at each grid point by changing the shift time
- Creation of a time-varying volume with 16 shift time steps



因果関係発見に向けて



1. 融合可視化
2. 因果ボリュームデータの可視化
3. 興味領域の特定
4. 特定された領域での因果関係発見

可視化：ビッグデータ時代の科学を拓く

可視化の性能評価

可視化研究と性能評価

医・理・工学

計測・計算

データ



どんな現象をデータ化
できたか？

情報科学

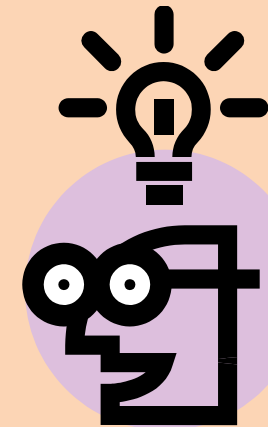
画像化



どれほど効率よく画像
化できたか？

認知科学

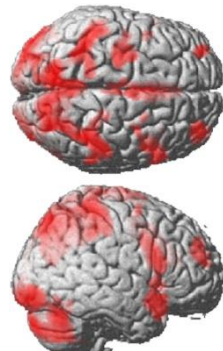
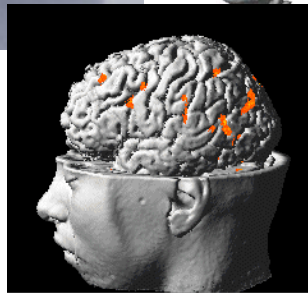
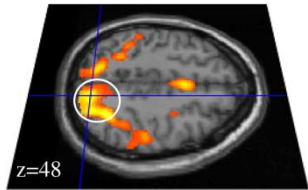
認識



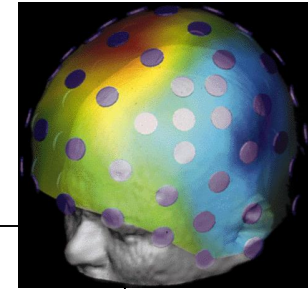
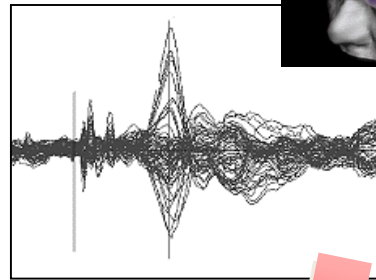
どれほどの気づきを得
たか、どんな行動変容
に結び付いたか？

脳機能計測装置による気付きの測定

MRI



MEG



EEG

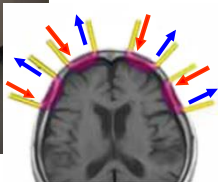
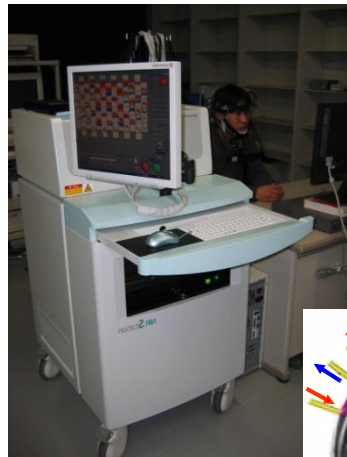


統合

時空間解像度

視覚的気付きの探索

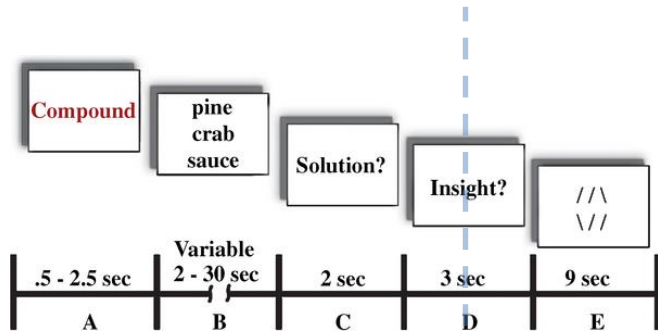
計算科学が拓く世界



NIRS

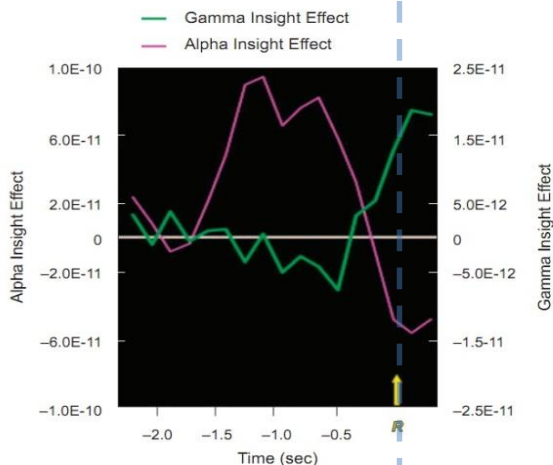
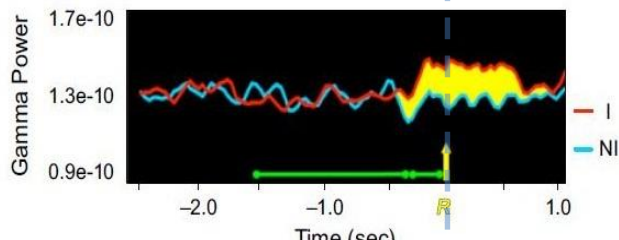
アハ体験についての研究

Kounios, J, Beeman, M, "The Aha! Moment-The Cognitive Neuroscience of Insight," 2009



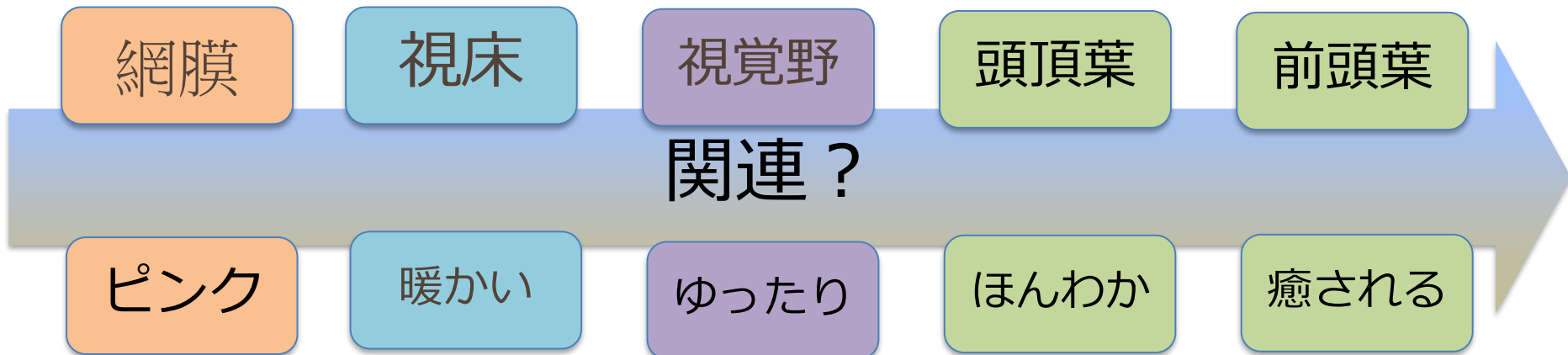
複合的遠隔性連想問題によるアハ体験

- ガンマ波 (約 40 ヘルツ) EEG 信号
- アルファ波 (約 10 ヘルツ) EEG 信号
- ひらめき時のガンマ波の組織的分布
- ひらめき時の機能的MRI分布



まとめ

- 科学的方法において重要な役割を果たす可視化研究
 - 粒子を用いた超拡張性可視化
 - 可視化による因果関係気付きの支援
 - 脳科学と連携する認知構造可視化



演習

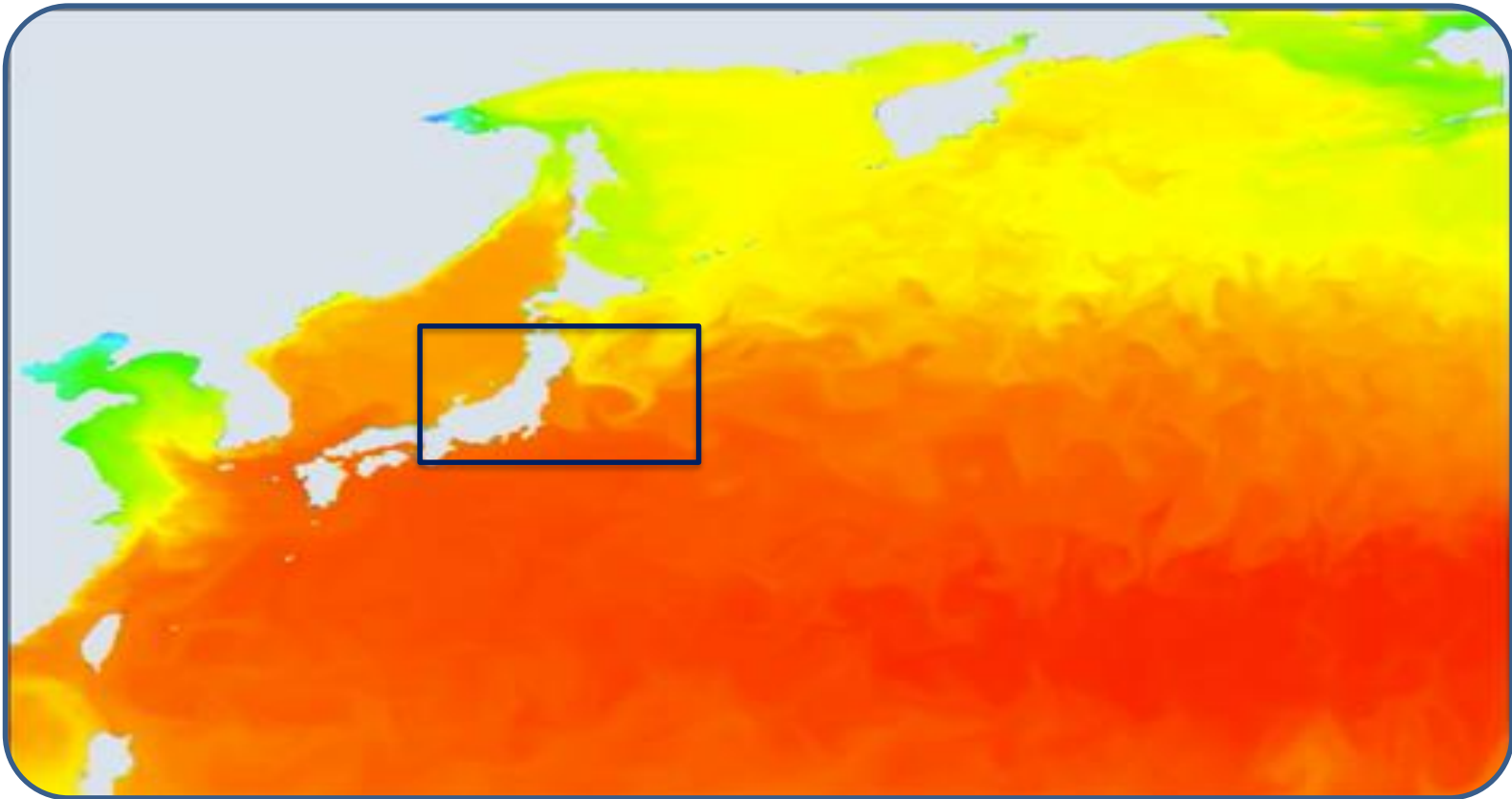
- 指定された論文を読み、小学生の著者が考えた仮説とその検証方法を回答せよ。
 - 以下サイトにアクセスして、200字程度で記述せよ

<https://goo.gl/6BgPxx>



俯瞰可視化

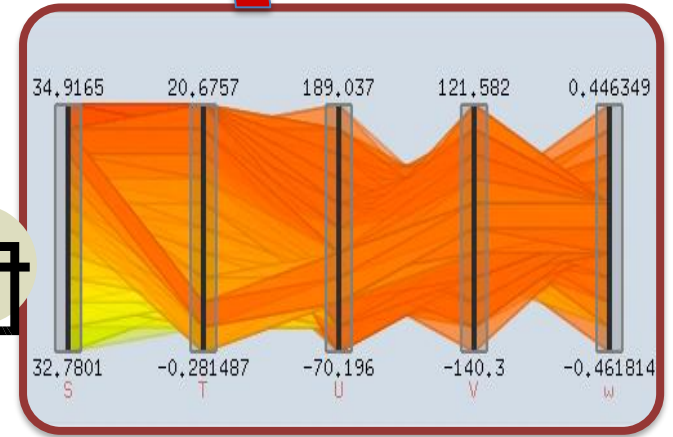
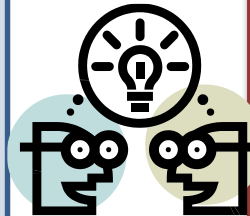
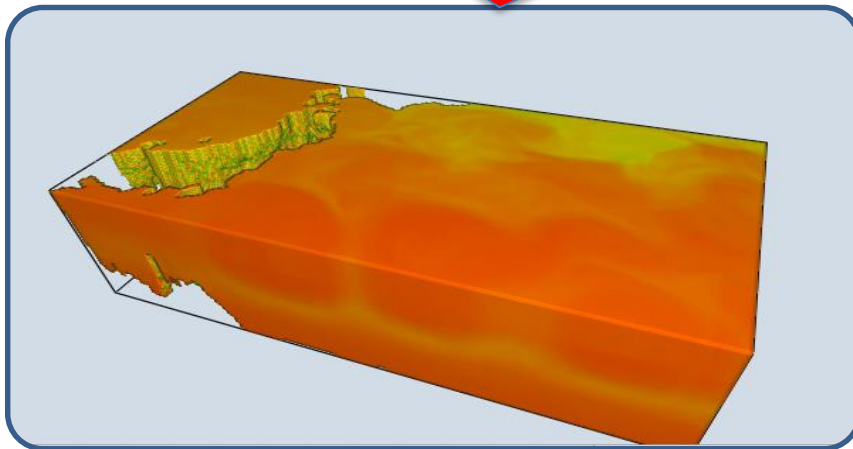
- 問題を設定
 - 全体領域を俯瞰的に可視化
 - 関心の高い領域を選択



拡大可視化

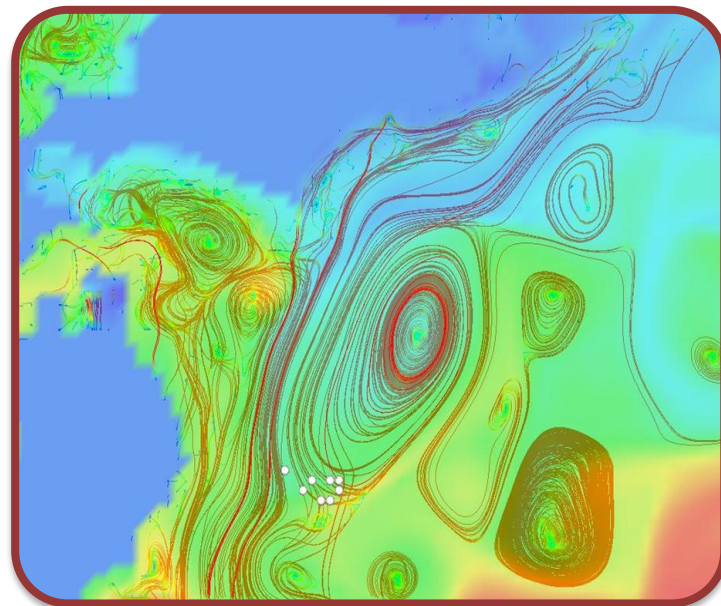
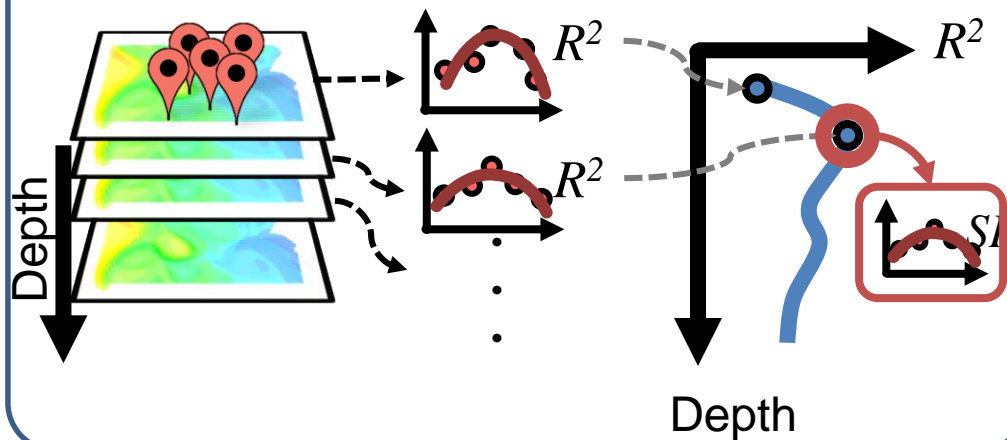
- 仮説を構築

- 緯度や経度の範囲を変化させて領域を切り出し
- 塩分濃度や海水温度の範囲を変化させて領域を切り出し



詳細可視化

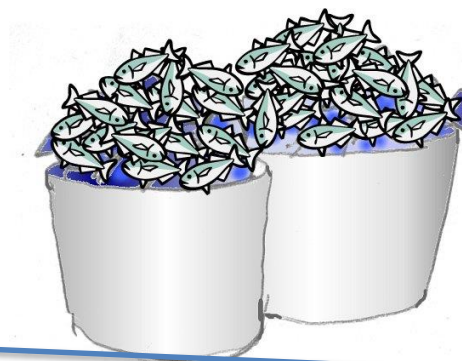
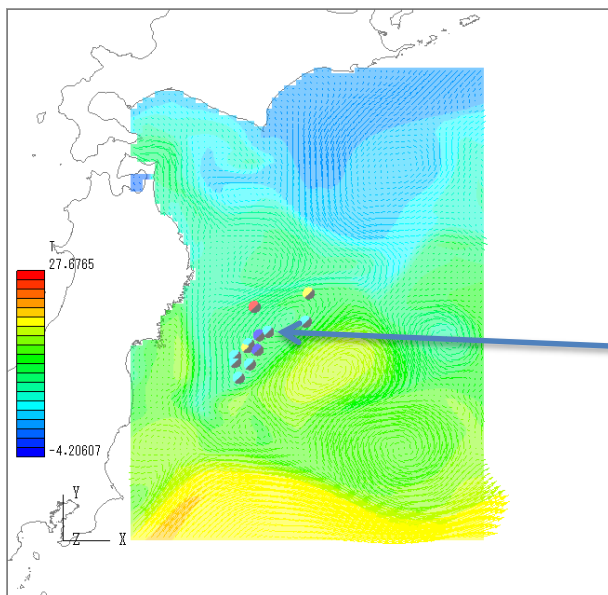
- 仮説を検証
 - 漁獲高をうまく説明する深さを探索
 - 漁獲高予測マップを作成する



漁師による漁獲量計測

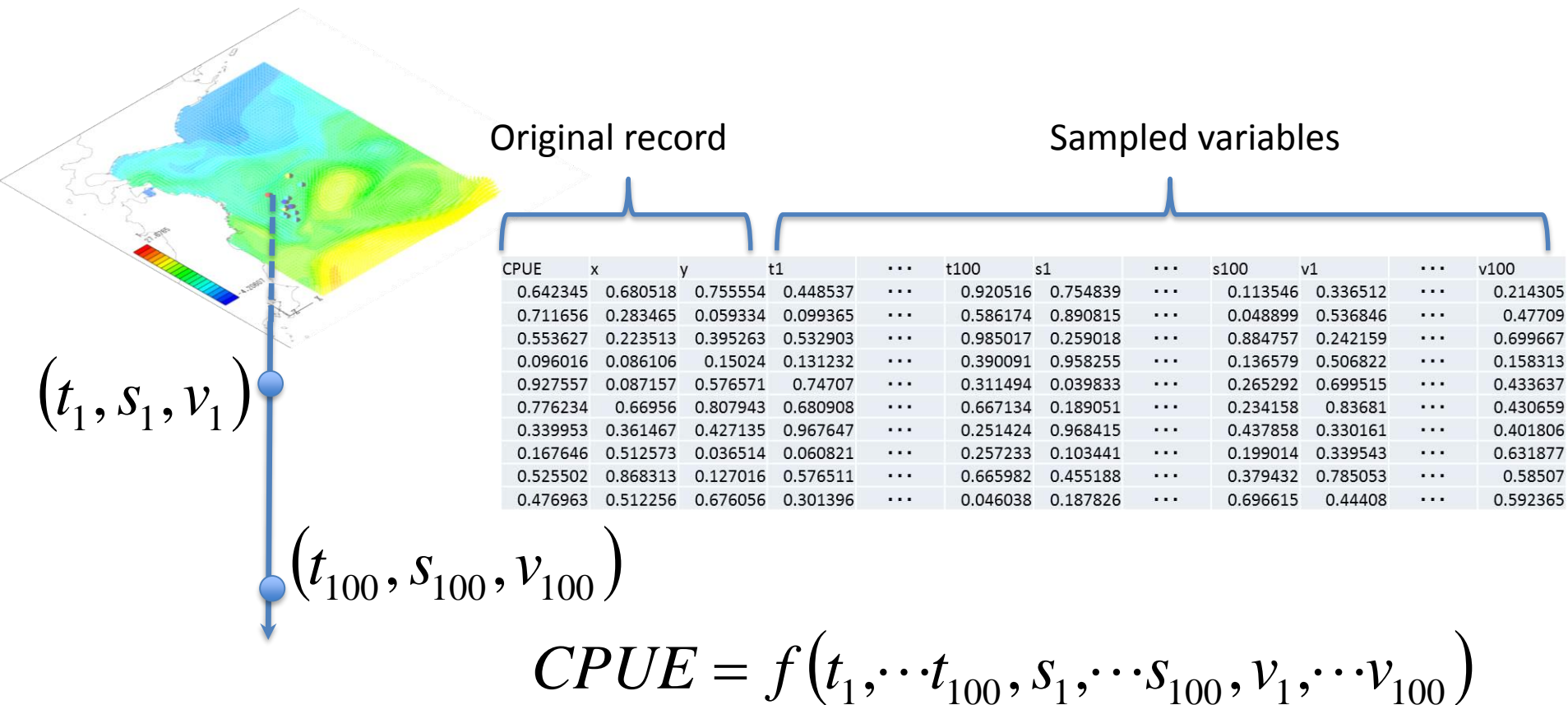
- 多くの漁師は以下の形式で漁獲量を計測し、記録
 - 漁船位置 (x,y)
 - 正規化漁獲量

$$CPUE = \frac{\sum catch}{\sum fishing\ days \sum fishing\ vessels}$$



CPUEをシミュレーション結果に含まれる変数で説明

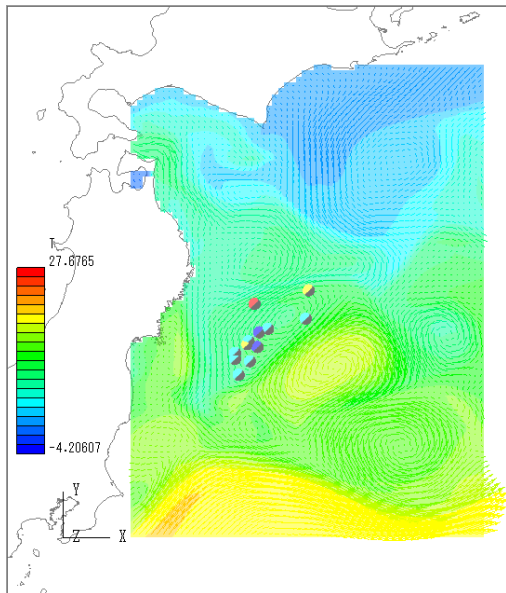
- シミュレーション結果においてCPUEの定義される点を通る鉛直線上でサンプリング



総合好適度(HSI) モデル

Tian, S., Chen, X., Chen, Y., Xu, L., Dai, X. 2009. Fisheries Research

- HSI は正規化されたCPUEを表す
- CPUEと高い相関を持つ変数を選択



CPUE	x	y	t1	...	t100	s1	...	s100	v1	...	v100
0.642345	0.680518	0.755554	0.448537	...	0.920516	0.754839	...	0.113546	0.336512	...	0.214305
0.711656	0.283465	0.059334	0.099365	...	0.586174	0.890815	...	0.048899	0.536846	...	0.47709
0.553627	0.223513	0.395263	0.532903	...	0.985017	0.259018	...	0.884757	0.242159	...	0.699667
0.096016	0.086106	0.15024	0.131232	...	0.390091	0.958255	...	0.136579	0.506822	...	0.158313
0.927557	0.087157	0.576571	0.74707	...	0.311494	0.039833	...	0.265292	0.699515	...	0.433637
0.776234	0.66956	0.807943	0.680908	...	0.667134	0.189051	...	0.234158	0.83681	...	0.430659
0.339953	0.361467	0.427135	0.967647	...	0.251424	0.968415	...	0.437858	0.330161	...	0.401806
0.167646	0.512573	0.036514	0.060821	...	0.257233	0.103441	...	0.199014	0.339543	...	0.631877
0.525502	0.868313	0.127016	0.576511	...	0.665982	0.455188	...	0.379432	0.785053	...	0.58507
0.476963	0.512256	0.676056	0.301396	...	0.046038	0.187826	...	0.696615	0.44408	...	0.592365
Correlation			0.419613	...	0.34039	-0.33172	...	-0.03077	0.477163	...	0.08621

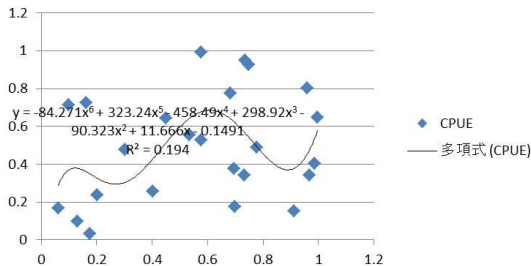
$$HSI = g(t_1, t_{100}, v_1) = \sqrt[3]{SI_1(t_1)SI_2(t_{100})SI_3(v_1)}$$

好適度(SI)

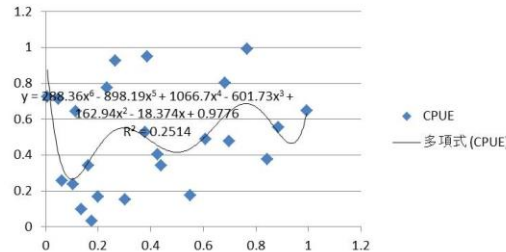
- SI 方程式はそれぞれの変数の回帰式で表現される。

$$HSI = \sqrt[3]{SI_1(t_1)SI_2(t_{100})SI_3(v_1)}$$

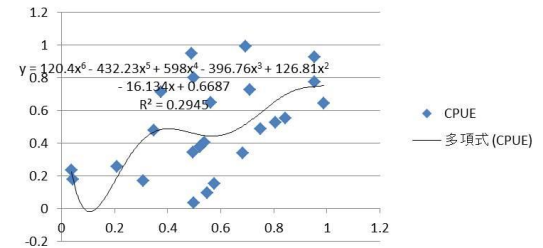
CPUE



CPUE



CPUE



$$HSI = \sqrt[n]{\prod_{i=1}^n SI_i}$$

$$SI_i = \frac{CPUE_{fit_i} - \min CPUE_{fit_i}}{\max CPUE_{fit_i} - \min CPUE_{fit_i}}$$

HSI モデル開発の手順

以下の手順でモデルを開発する:

1. CPUEと高い相関を持つ変数を選択し、SI方程式を構築
2. SI方程式の相乗平均としてHISを構築
3. モデル妥当性検証のためにHIS分布を可視化

