

Visual Causality Exploration and its applications

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Kyoto University
Koji KOYAMADA

Content

- Background
- What is scientific discovery?
- Visual Causality exploration
 - Time series data from measurement/computing
 - Exploring a latent factor
- Summary

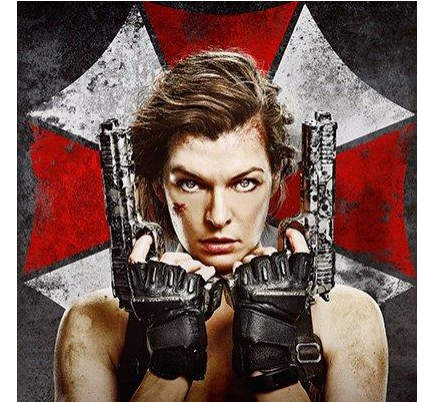
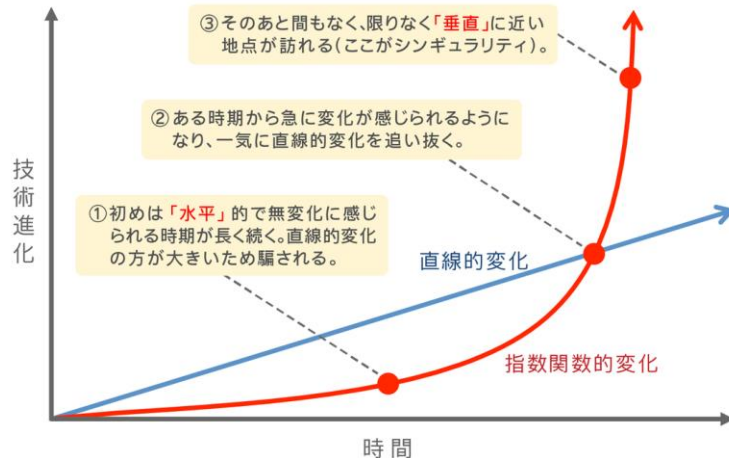
Does visualization contribute to the scientific discovery ?

Visual Causality Exploration and its applications

BACKGROUND

Coming of Technological Singularity

<https://dentsu-ho.com/articles/3260>



<http://www.imdb.com/title/tt2592614/>

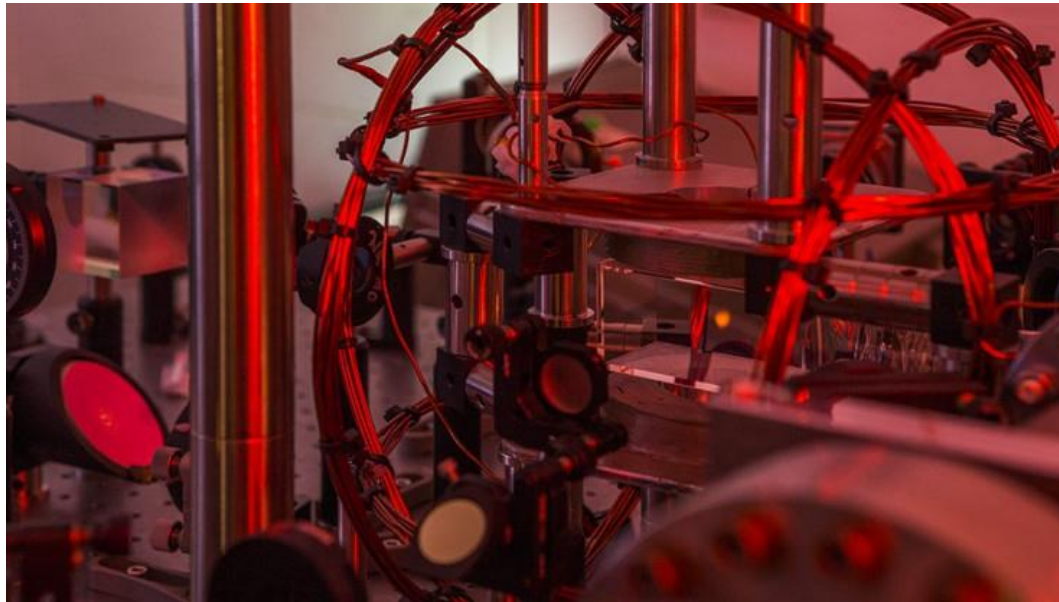
http://www.impawards.com/2015/terminator_genisys_ver6.html

- There is a hypothesis that technology will make innovative progress by 2045 and transform society drastically.
- This theory is called a technological singularity, or 2045 problem.
- There is a forecast that this first super-intelligent machine by this technology will be the last invention of human being.

AI Scientist

<https://techcrunch.com/2016/05/16/ai-learns-and-recreates-nobel-winning-physics-experiment/>

- AI learns and recreates Nobel-winning physics experiment
 - AI performed the experiment on the creation of a Bose-Einstein condensate, a hyper-cold gas.
 - Three physicists won the Nobel Prize in 2001 for the process.



Joint Workshop 2017

Big Data Era

From Science Projects to Social Networks to Smart Technology



Finding Answers where there are yet to be Questions...

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

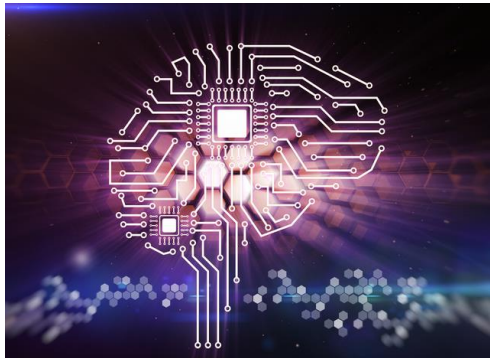
Joint Workshop 20

1.8 zeta bytes in 2011

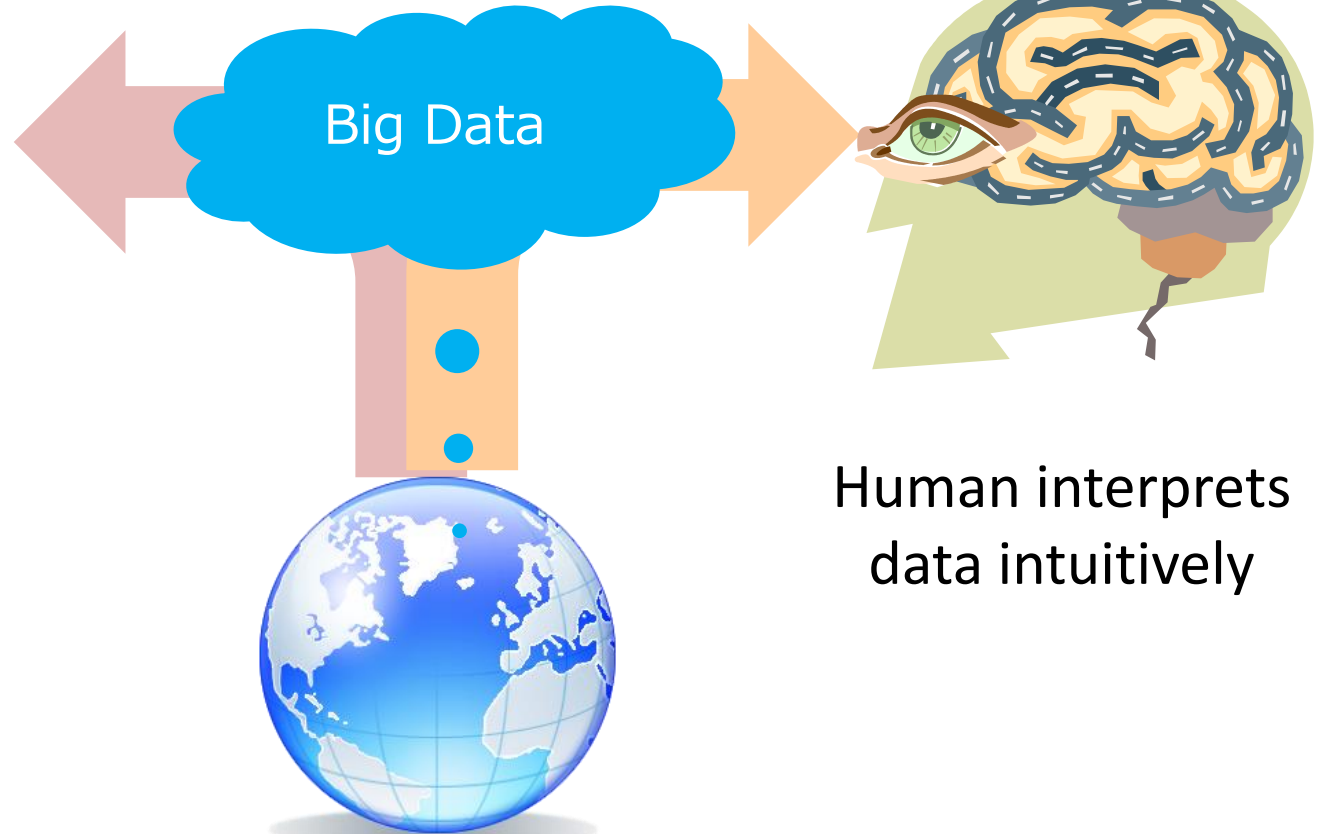
Human Machine Collaboration

<http://www.npr.org/programs/ted-radio-hour/522858434/the-digital-industrial-revolution?showDate=2017-04-21>

- The human might lead, but the computer can do lots of fancy moves that together combine into something...



Machine (AI)
processes data
efficiently



Human interprets
data intuitively

Data and Information

Data

What something is coded to

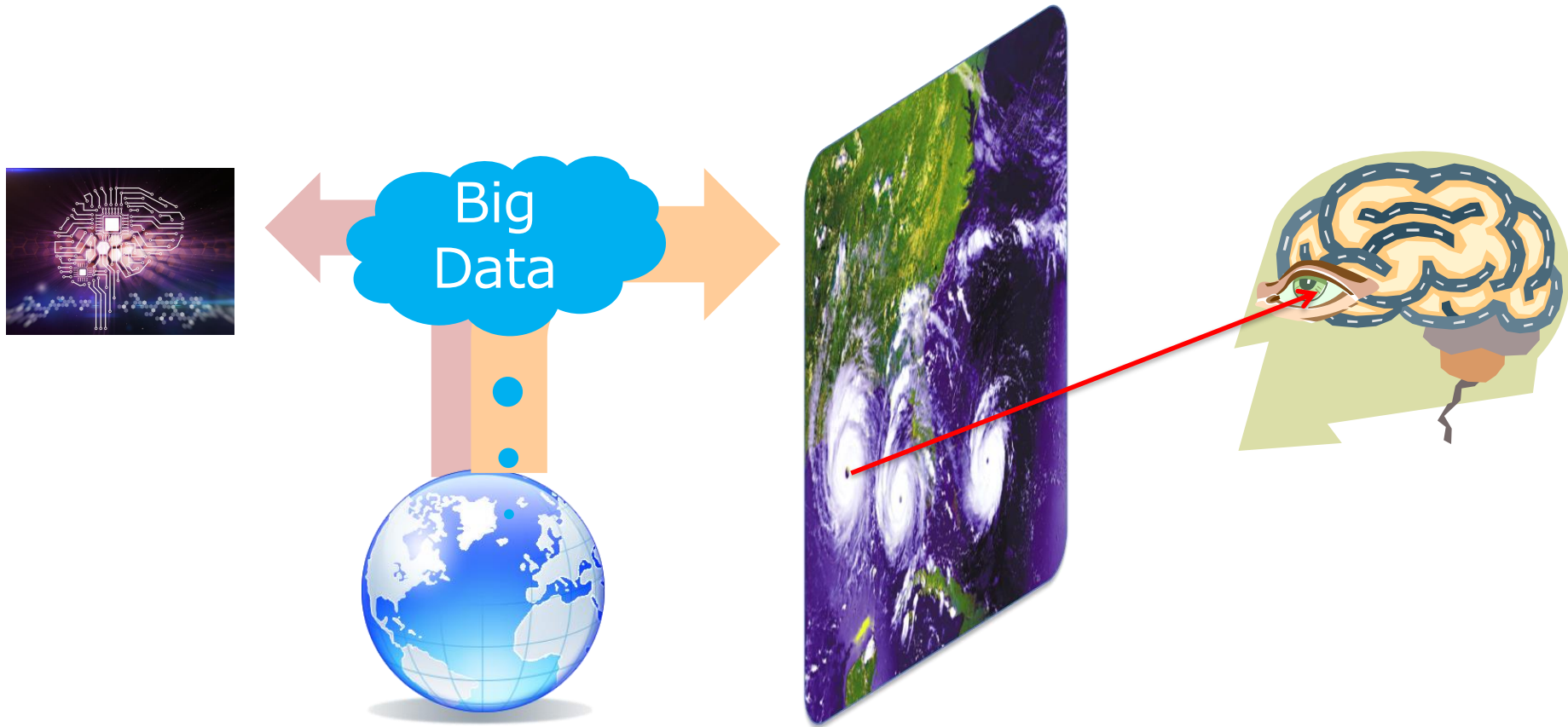
Visualization

Information

Data interpreted by human beings

Visualization

Essential for human and machine collaboration



Visualization Research

Natural / Social
Science

Measurement/
Computing

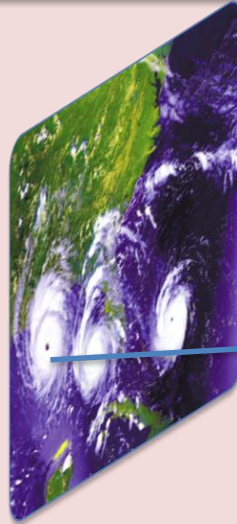
Big
Data



What kind of important
phenomenon do you
convert into data?

Computer science

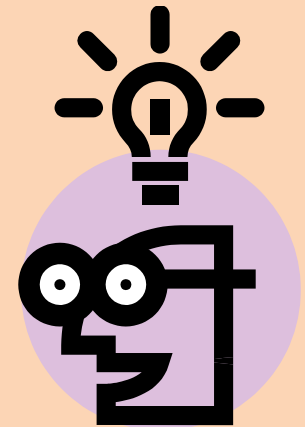
Image
synthesis



How efficiently do you
generate images from
data?

Cognitive science

Cognition



How much inspiration
do you get from that
image?

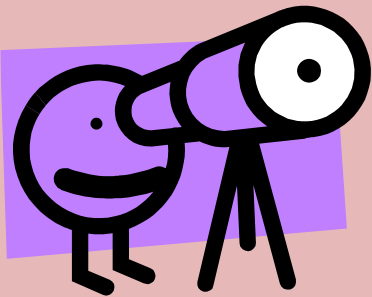
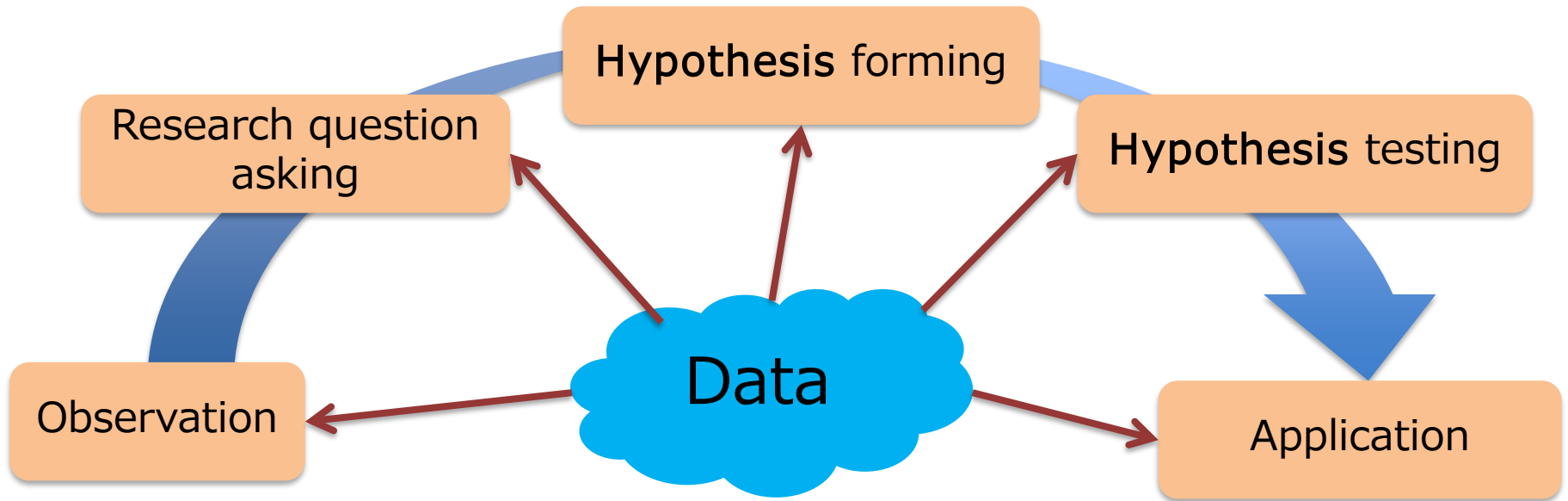
Data visualization techniques

Visual analytics

Visual Causality Exploration and its applications

WHAT IS SCIENTIFIC DISCOVERY?

Scientific Method



What is Research question ?

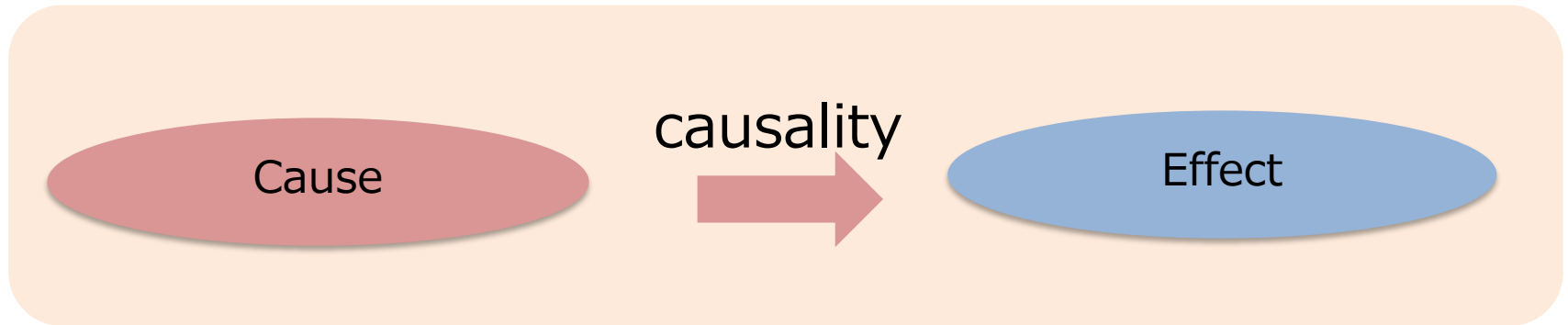
- The most important part of the scientific method derived from the observation.
- Example: “Why does the increase of Carbon dioxide concentration facilitate the global warming ? ”



Effect

Forming Hypothesis to explain the effect

Hypothesis



- It states a presumed relationship between two variables in a way
- It can be tested with empirical data.
- It may take the form of a **cause-effect** statement, or an "if x,...then y" statement.

Causality exploration is essential in scientific discovery

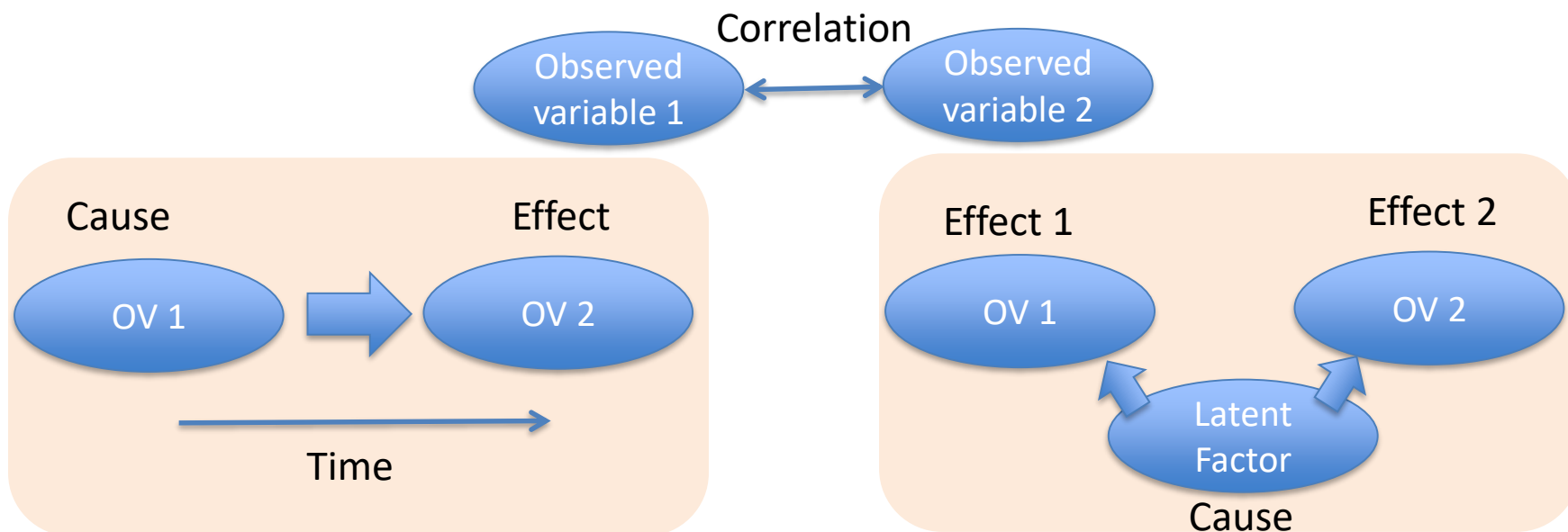
What is Science ?

M. Harada, Science for kids, The first issue, Oct. 1924



Clarify a causal relationship
between things

Correlation does not imply causation



Visual Causality Exploration and its applications

TIME SERIES DATA FROM MEASUREMENT/COMPUTING

Causality between time series data sets

causality ?

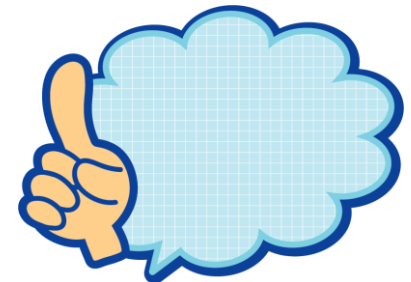
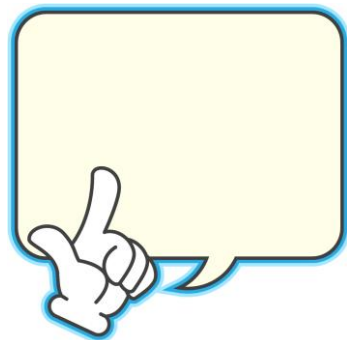
Cause

Effect

Cause

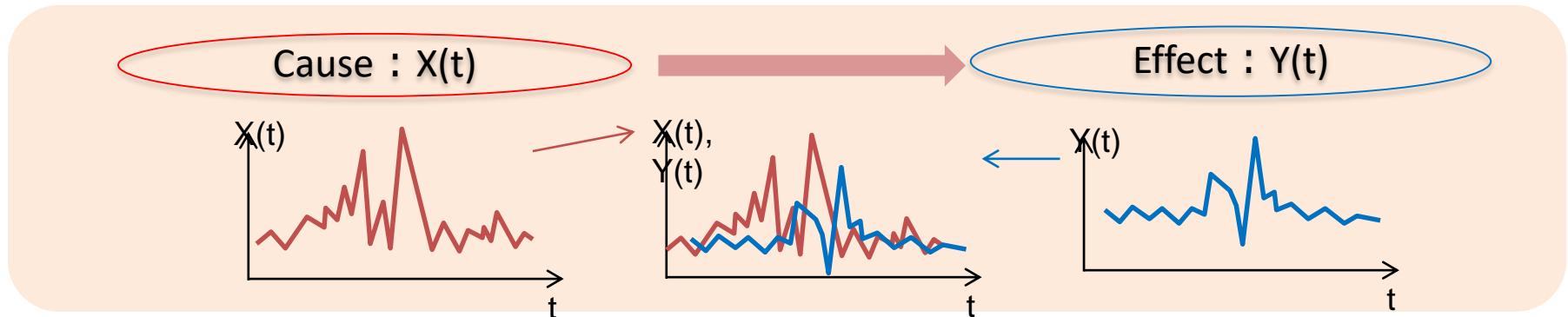
Effect

t



Causality discovery techniques

- Causality is the relation between one process (the cause) and another (the effect), where the first is understood to be partly responsible for the second.



Granger Causality

- Test of significant difference of explanation capability by multivariate autoregressive model
- Application Example: causality of the currency amount and income, etc.
- 1969, Clive Granger



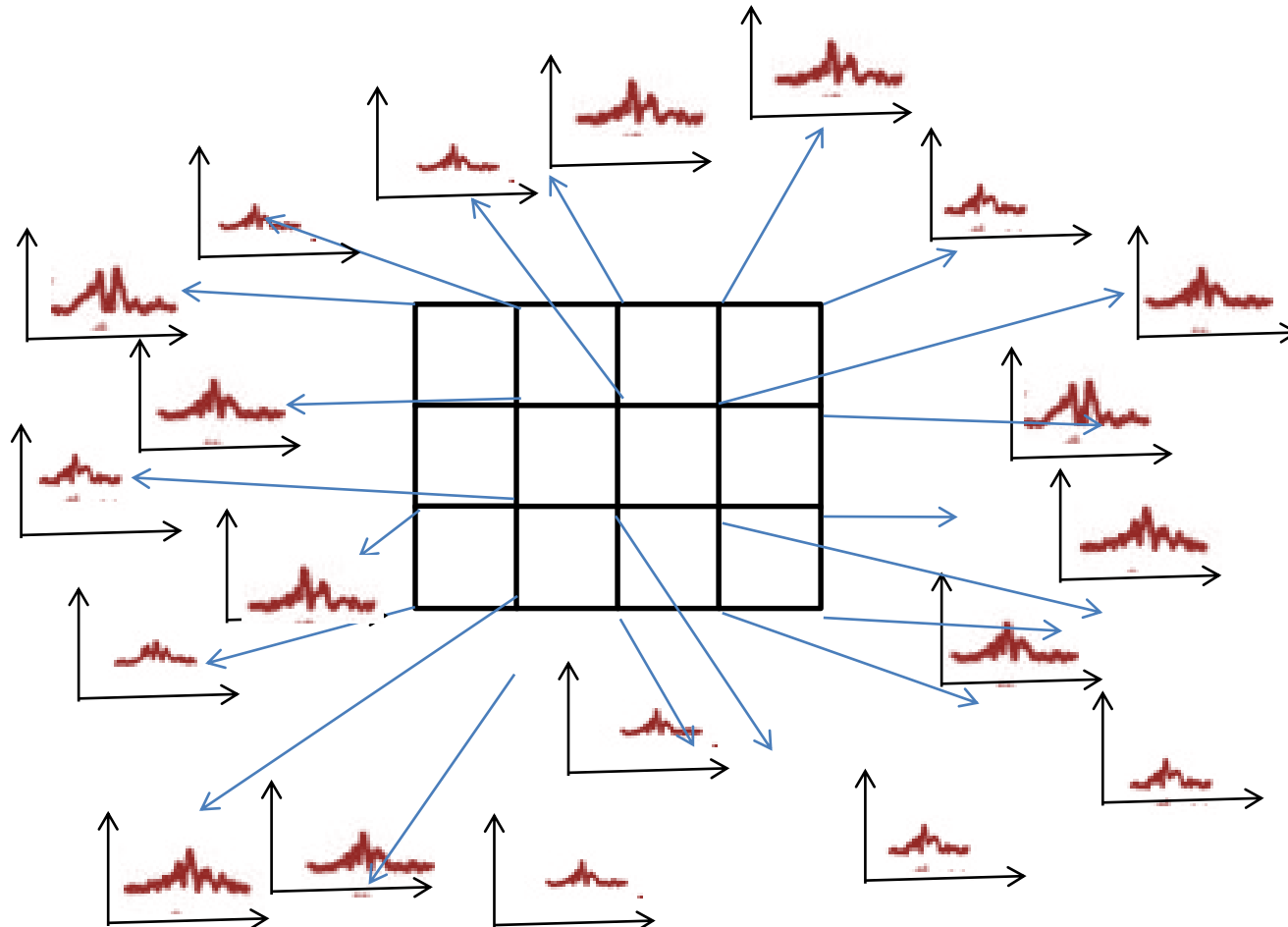
Convergent Cross Mapping

- Evaluation of synergistic effect between variables using the Takens' embedding theorem
- Application Example: Causality between anchovy and sardine catches, etc.
- 2012, George Sugihara



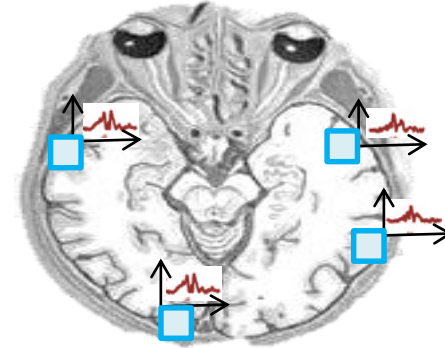
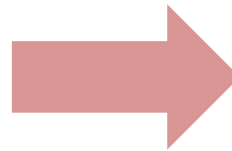
Time-varying univariate volume

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

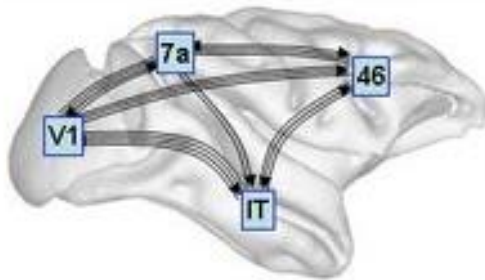


Causality in brain science

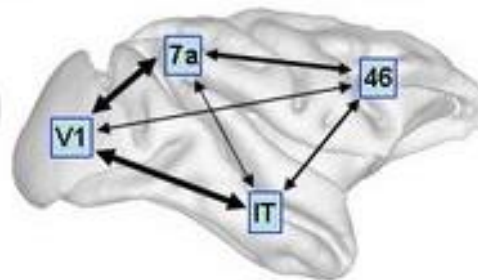
RQ: Why does the functional neuroimaging represent the effective connectivity ?



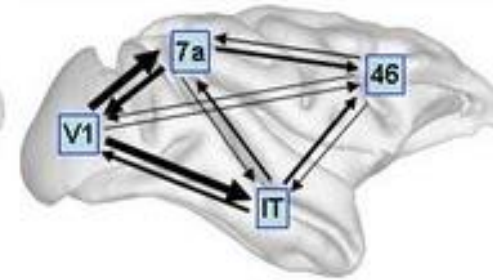
structural connectivity



functional connectivity



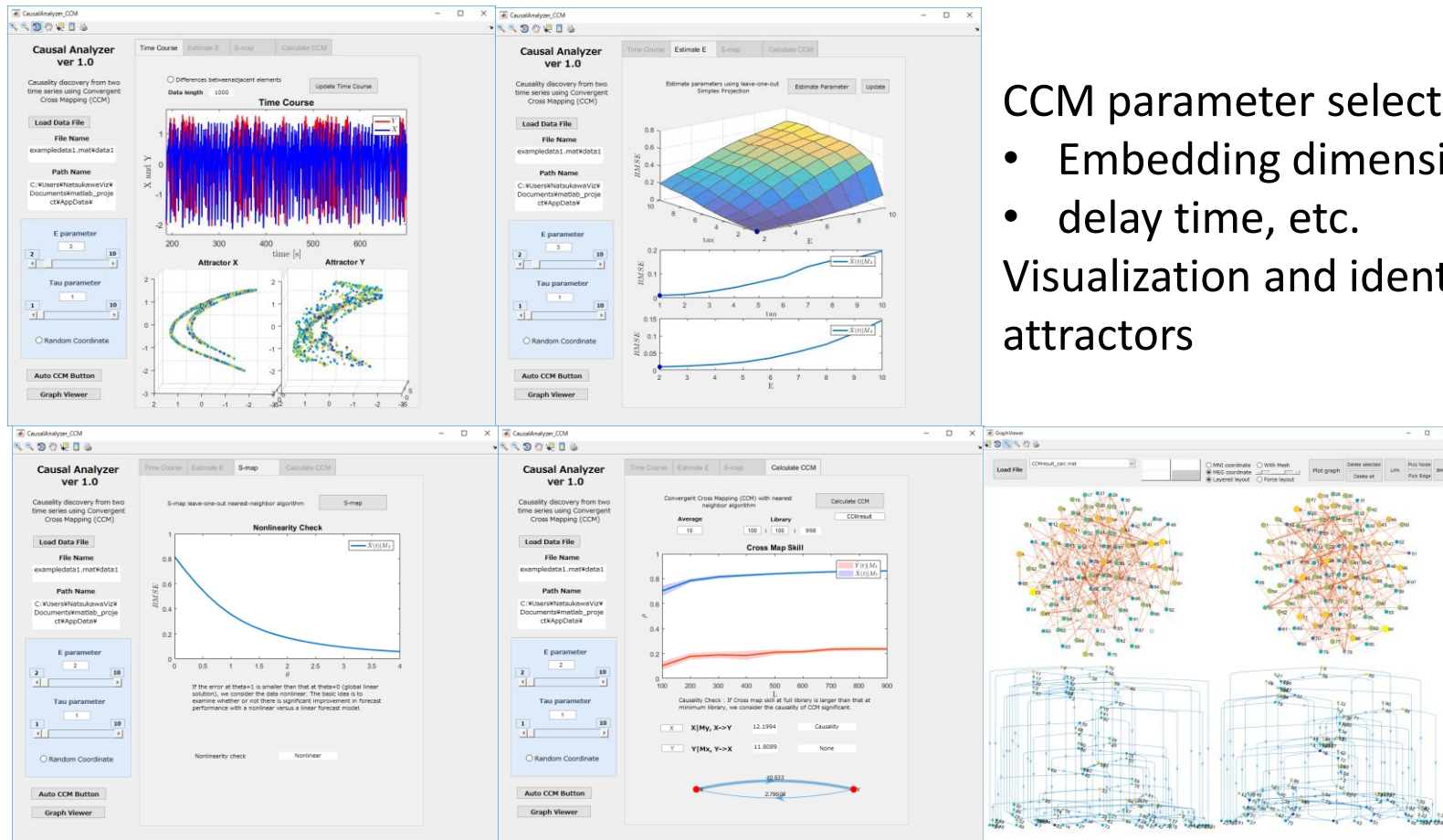
effective connectivity



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

CCM-based effective connectivity analysis



CCM parameter selection

- Embedding dimension
- delay time, etc.

Visualization and identification of attractors

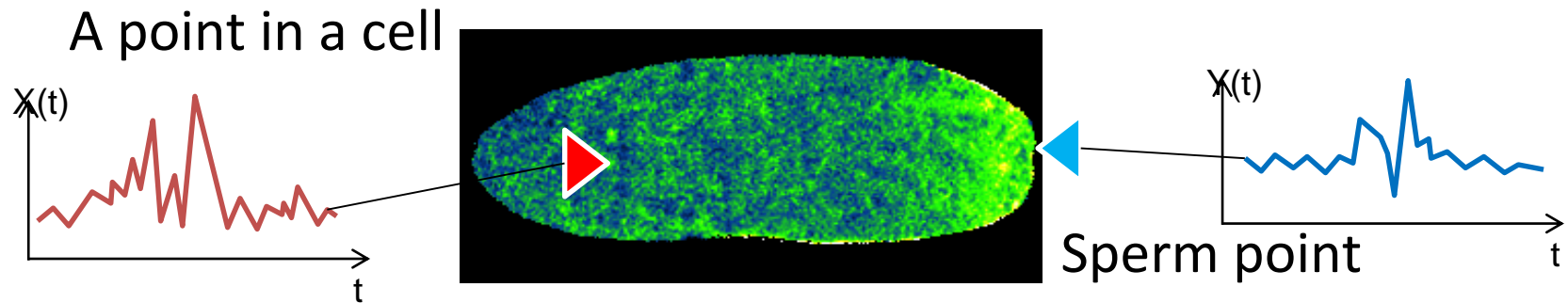
Visual analytic system for conducting CCM procedure

Causality in life science

RQ: Why does the Ca^{2+} wave facilitate the fertilization ?

- Calcium Wave in the Oocyte

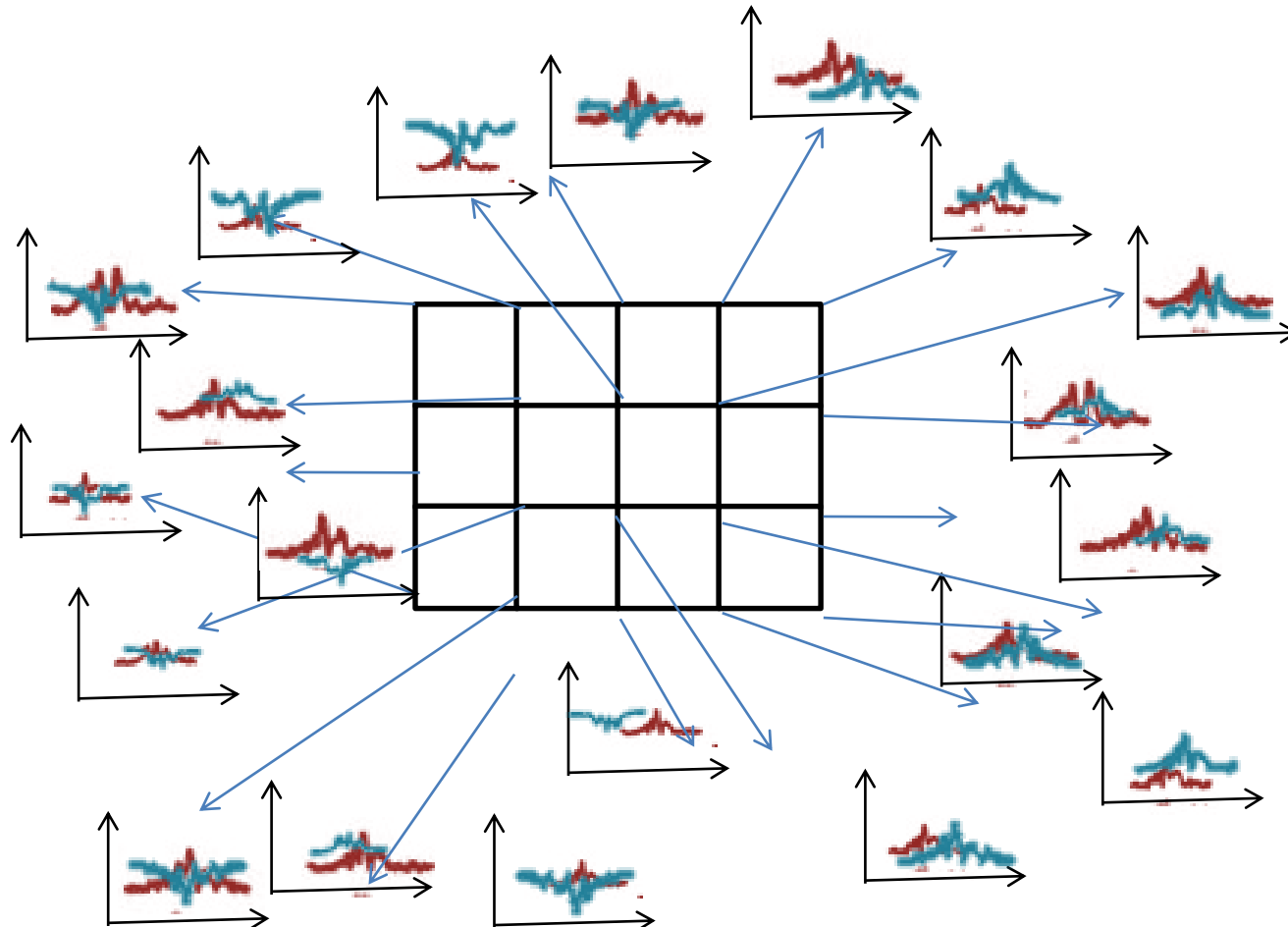
- The occurrence of a Ca^{2+} wave is a common phenomenon during fertilization
- The mechanism of a Ca^{2+} wave has not been fully elucidated



Exploring the internal structure of the Oocyte

Time-varying bivariate volume

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



Causality in earth science

RQ: Why do some meteorological variables forecast the rainfall ?

Extreme rainfall phenomena

- ① Meteorological data causes rainfall data
- ② Rainfall data causes water level data



Meteorological

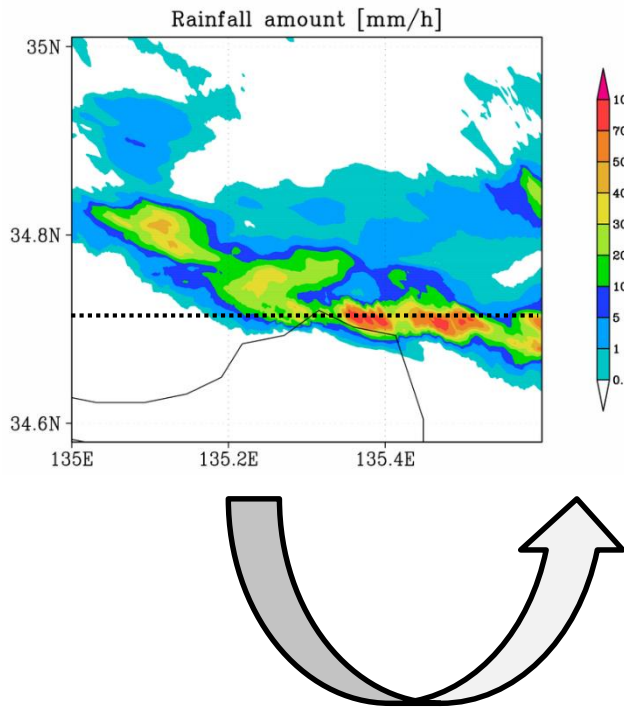
Rainfall

Water level

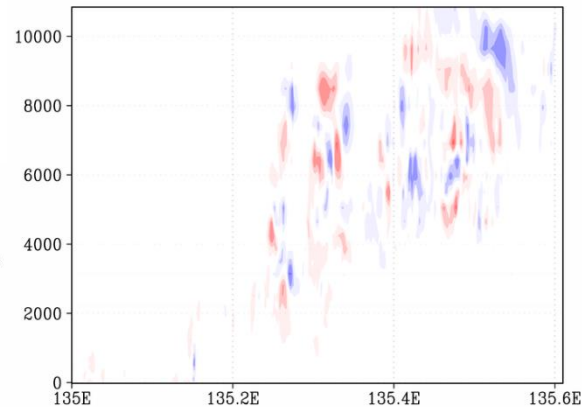
Can we forecast water level from meteorological data ?

Meteorological data in the sky

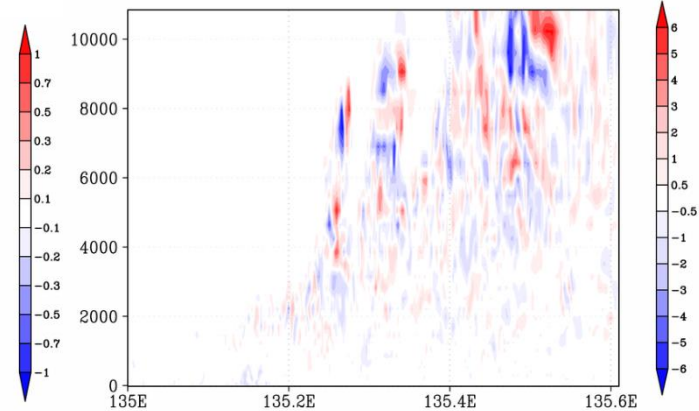
Rain fall (03:20 UTC)



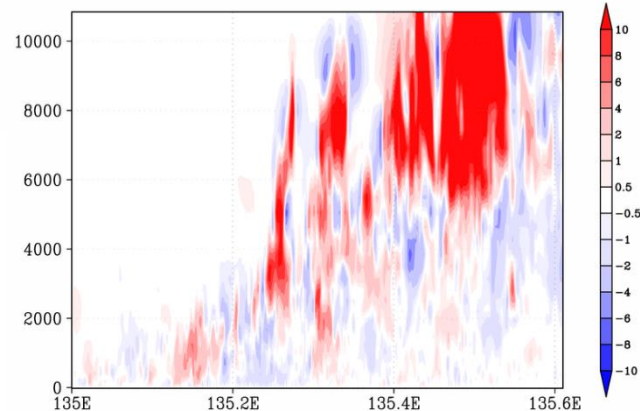
Pressure derivative



Temperature derivative



Vertical velocity



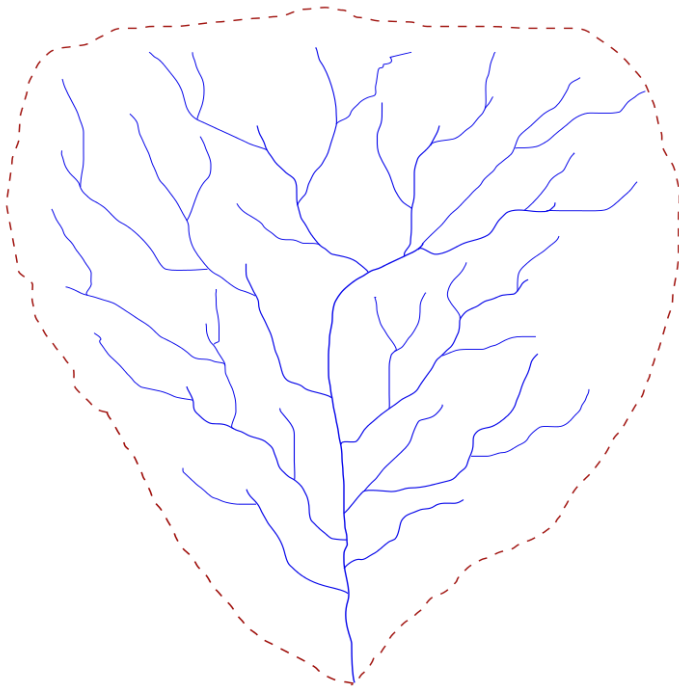
Data courtesy: Dr. Miyoshi in RIKEN



Can the rainfall can be explained by the weather data ?

Rainfall in a drainage basin

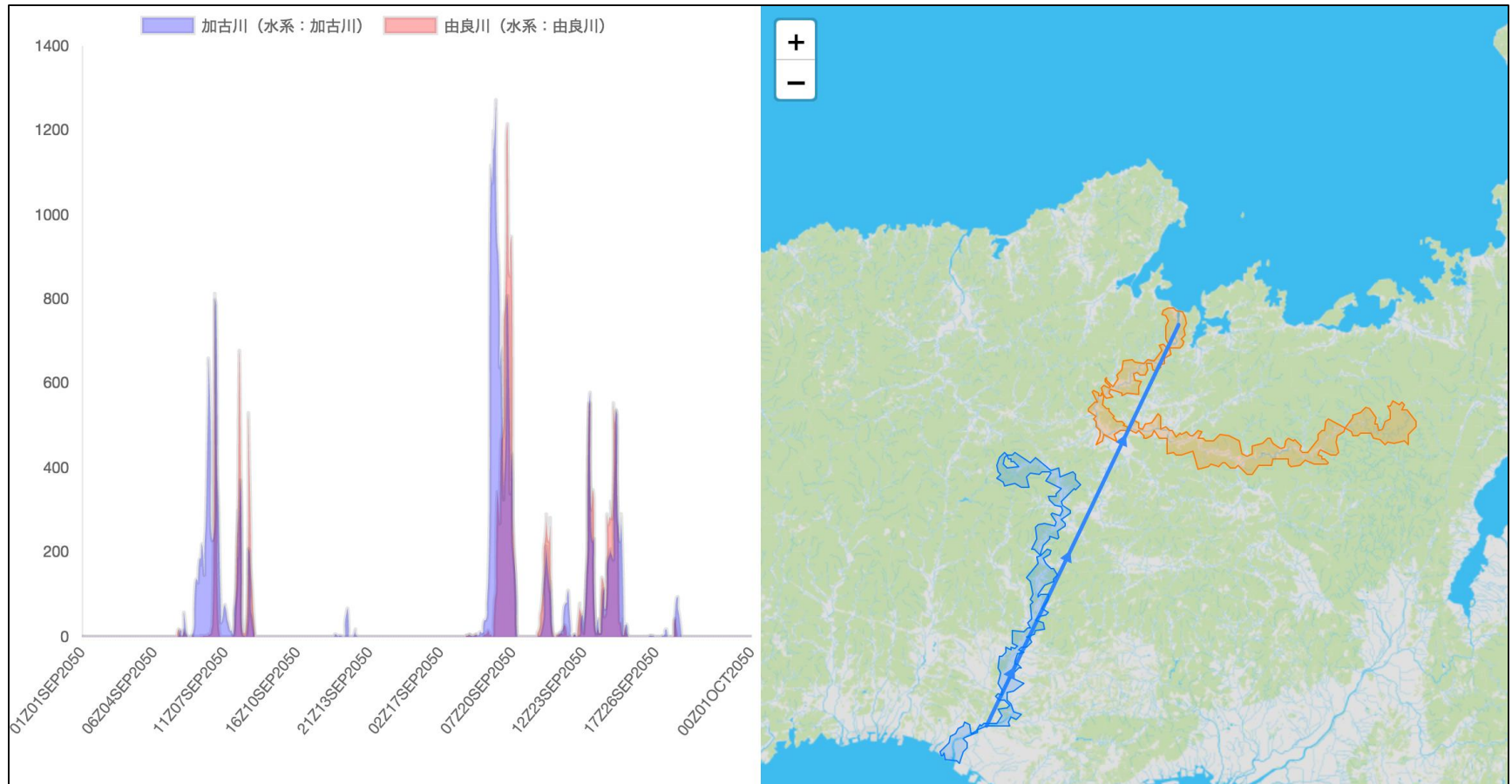
<https://commons.wikimedia.org/w/index.php?curid=479566>



Can the water level be explained by the rainfall ?

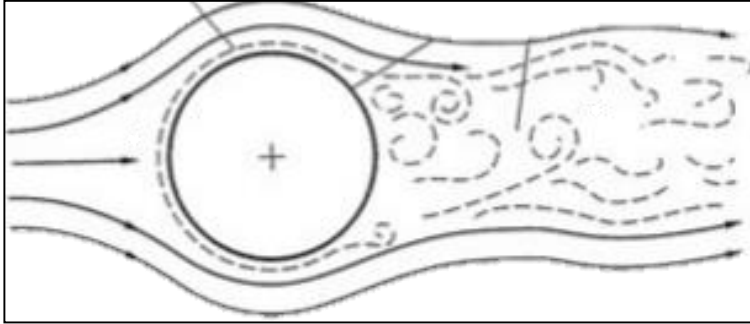
<https://baike.baidu.com/item/%E9%9B%86%E6%B0%B4%E5%8C%BA?fromtitle=drainage+basin&fromid=11323701>

Causality between the specified rainfalls



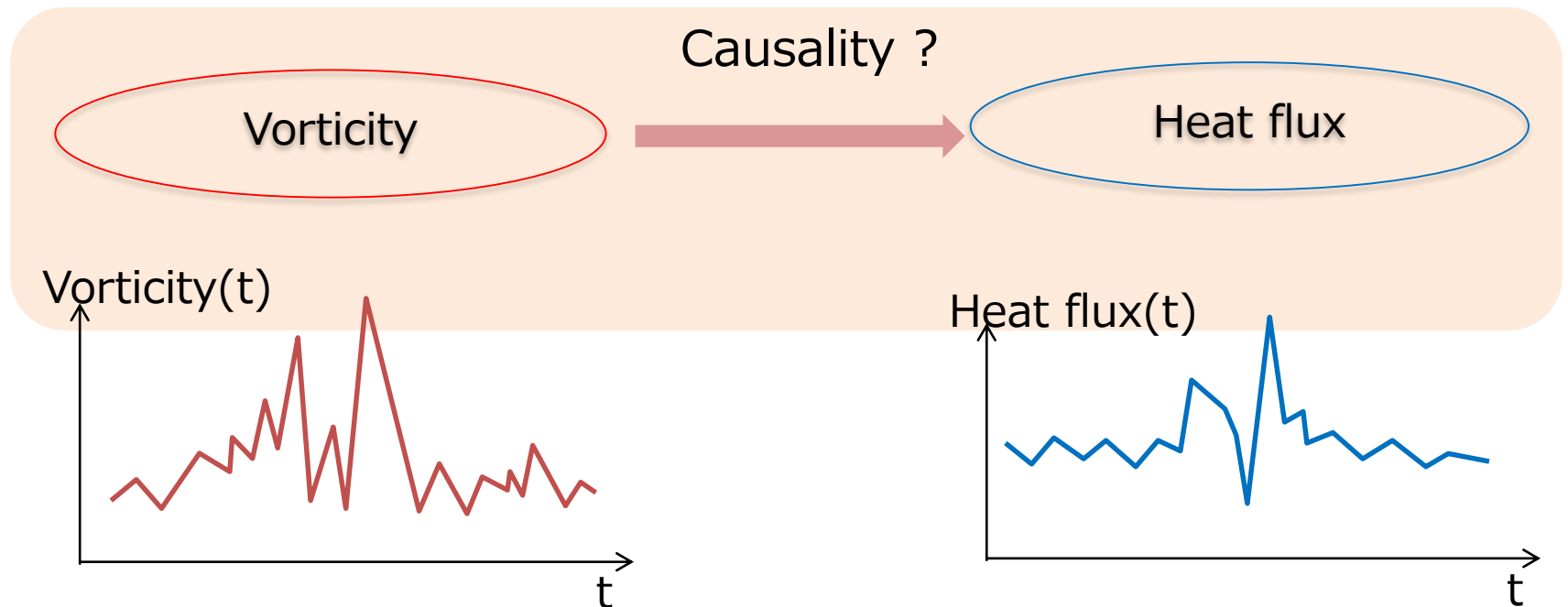
Causality in fluid science

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



Washing effect

- The vortex flow contributes to the enhancement of the heat transfer

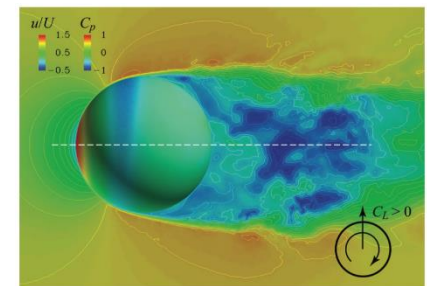
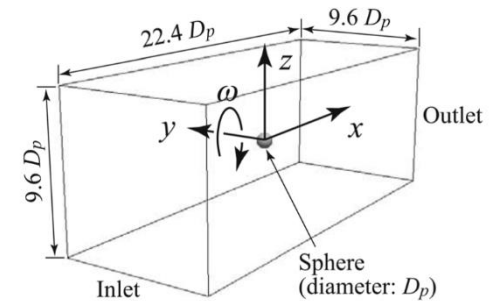


Airflow around a heated sphere

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

- Model description

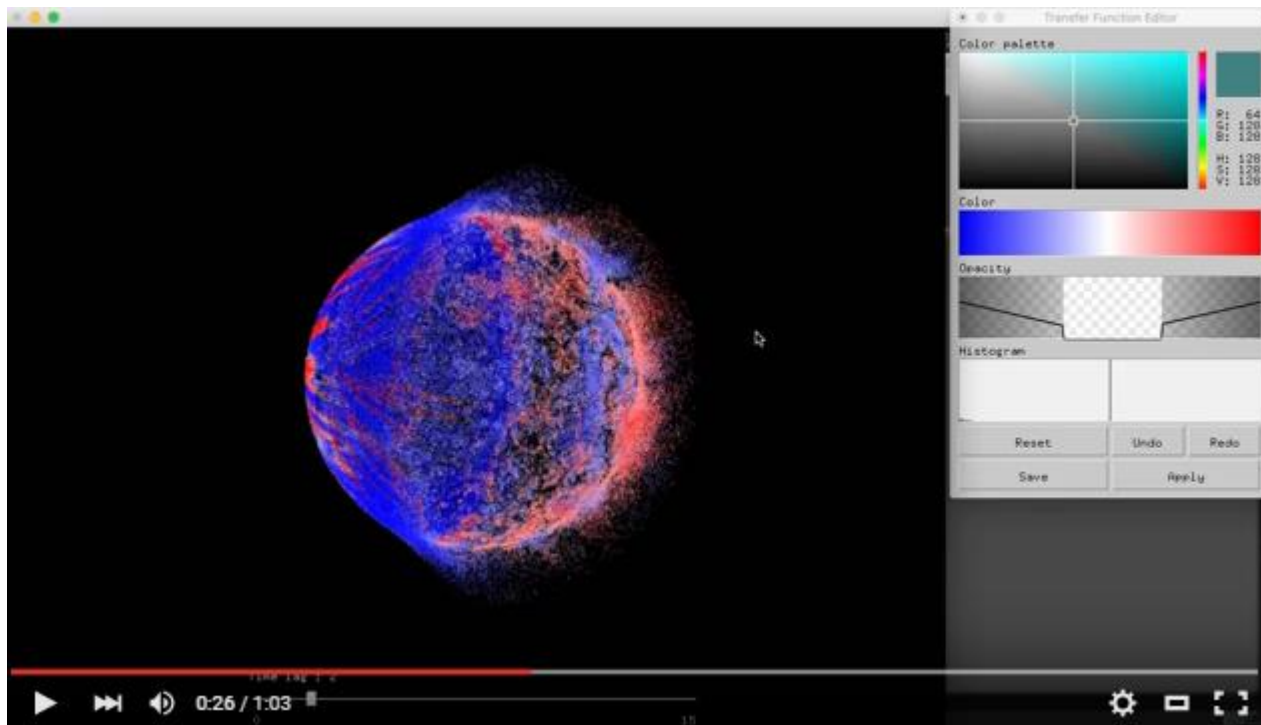
- Number of nodes : 15,321,546
- Number of cells : 18,917,887 (prism)
27,545,304 (tet)
- Number of time steps : 198
- File size : 3.5GB per step



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

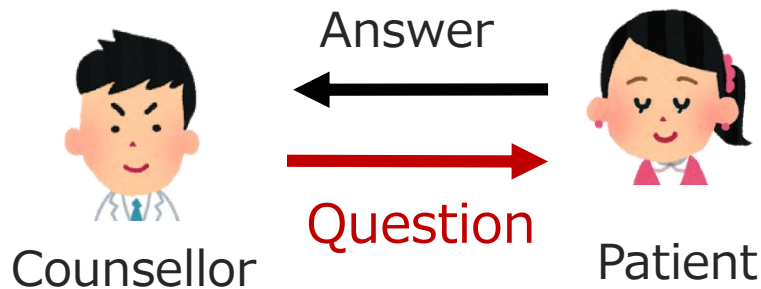
Causal volume visualization

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



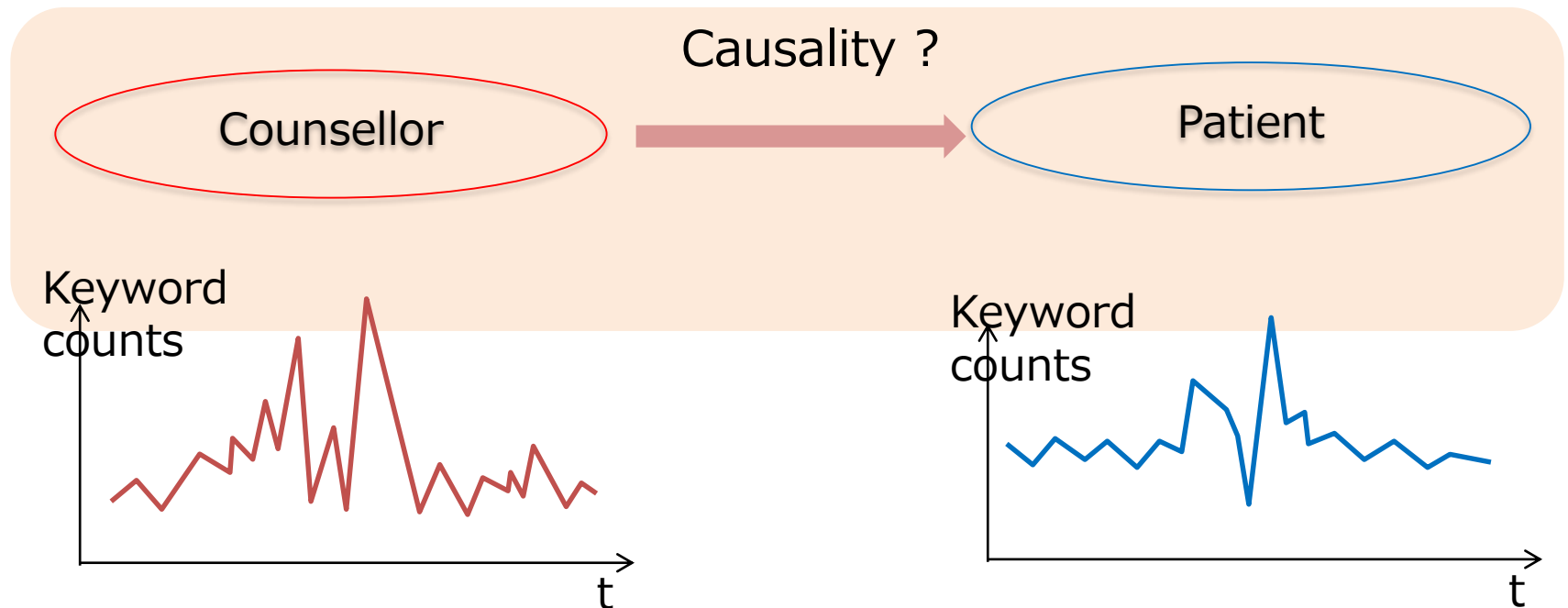
Causality in communication science

RQ: Why do the counsellor's provision relax the patient's problem ?



Counselling

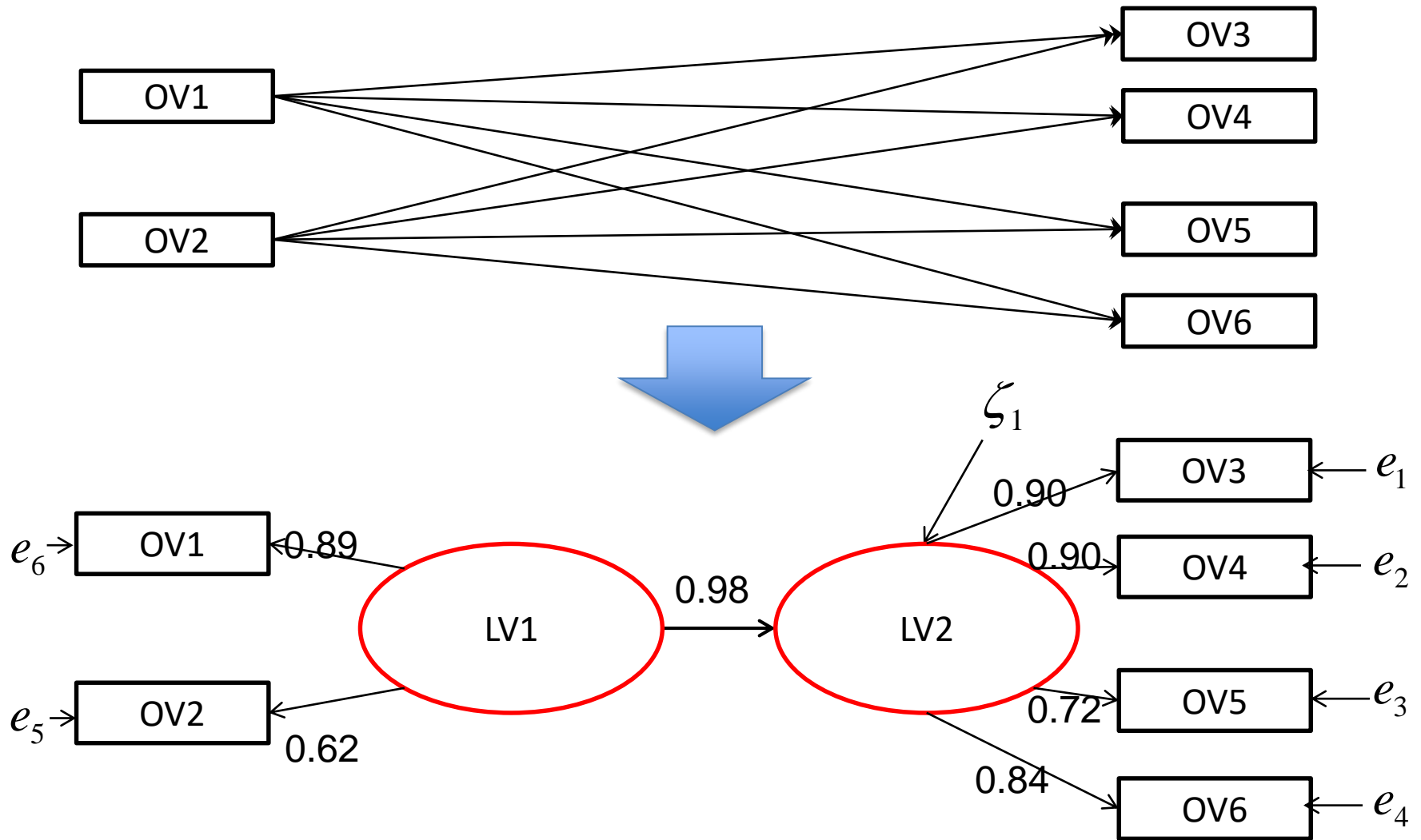
- The provision of professional assistance and guidance in resolving personal problems.



Visual Causality Exploration and its applications

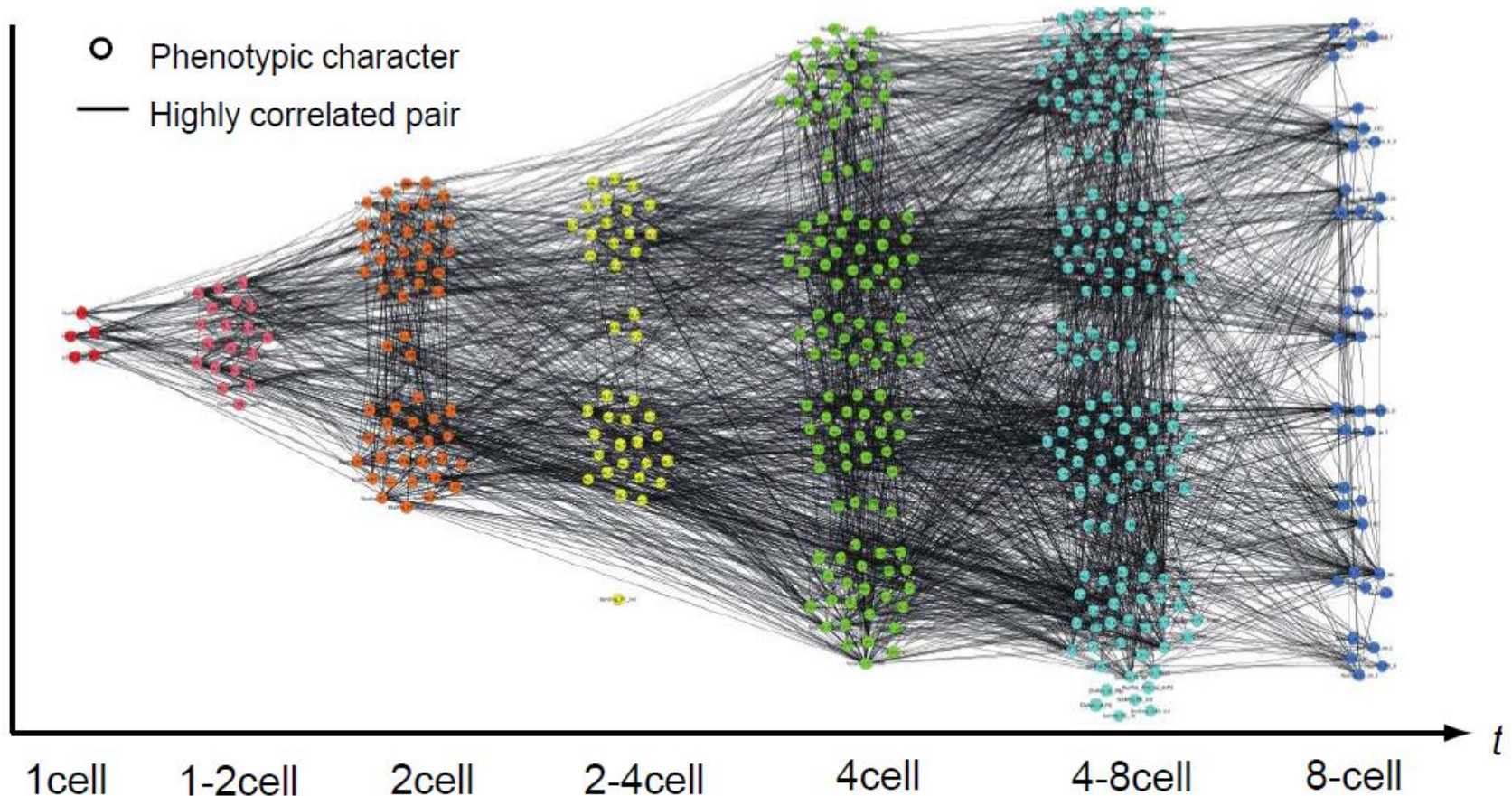
EXPLORING A LATENT FACTOR

Modeling of latent variables using Structural equation modeling (SEM)



Causality in life science

RQ: Why does not the genotype determine the phenotype ?
Correlations between phenotypic features in the early stages of embryo development of the *c. elegans*

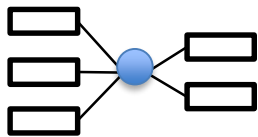
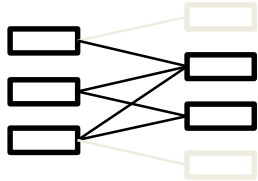
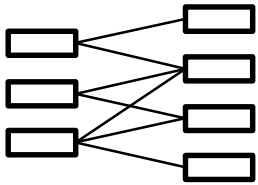


Data courtesy: Dr. Omani of RIKEN

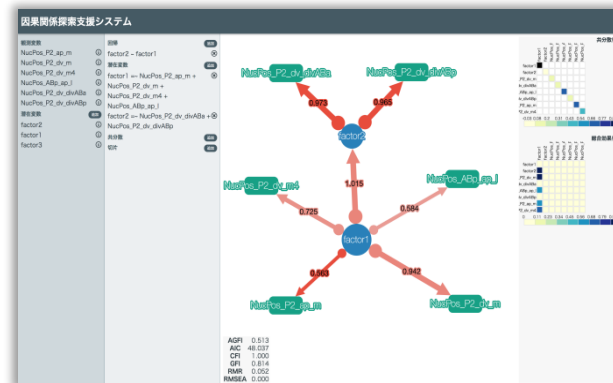
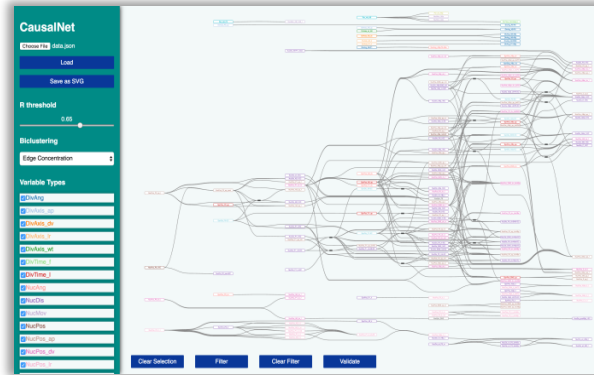
Visual mastermind exploration of phenotype network

Y. Onoue et. al, IEEE TVCG, 2016

Bi-Clustering



Extraction of a latent variable

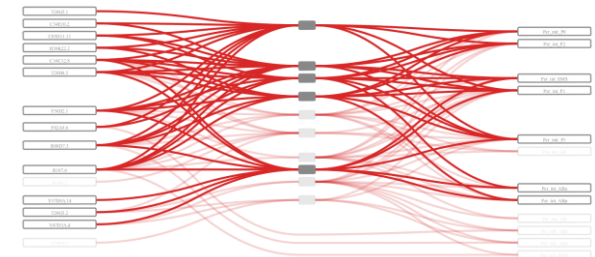


Hypothesis Forming

- Visualization of phenotype network using Sugiyama framework and Edge Concentration
- Extraction of candidate of latent variables Using Bi-Clustering

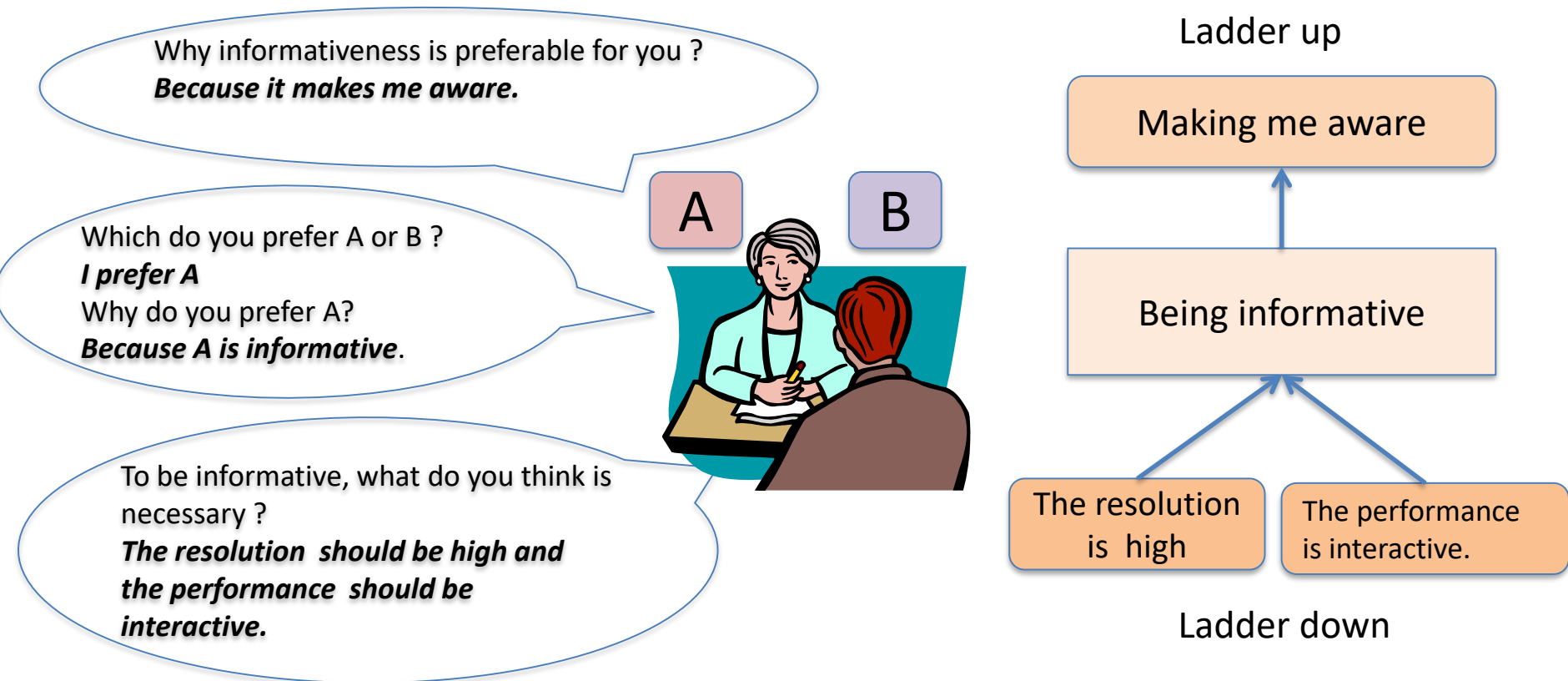
Hypothesis Testing

- Focusing on ROI sub-graph
- Interactive statistical analysis



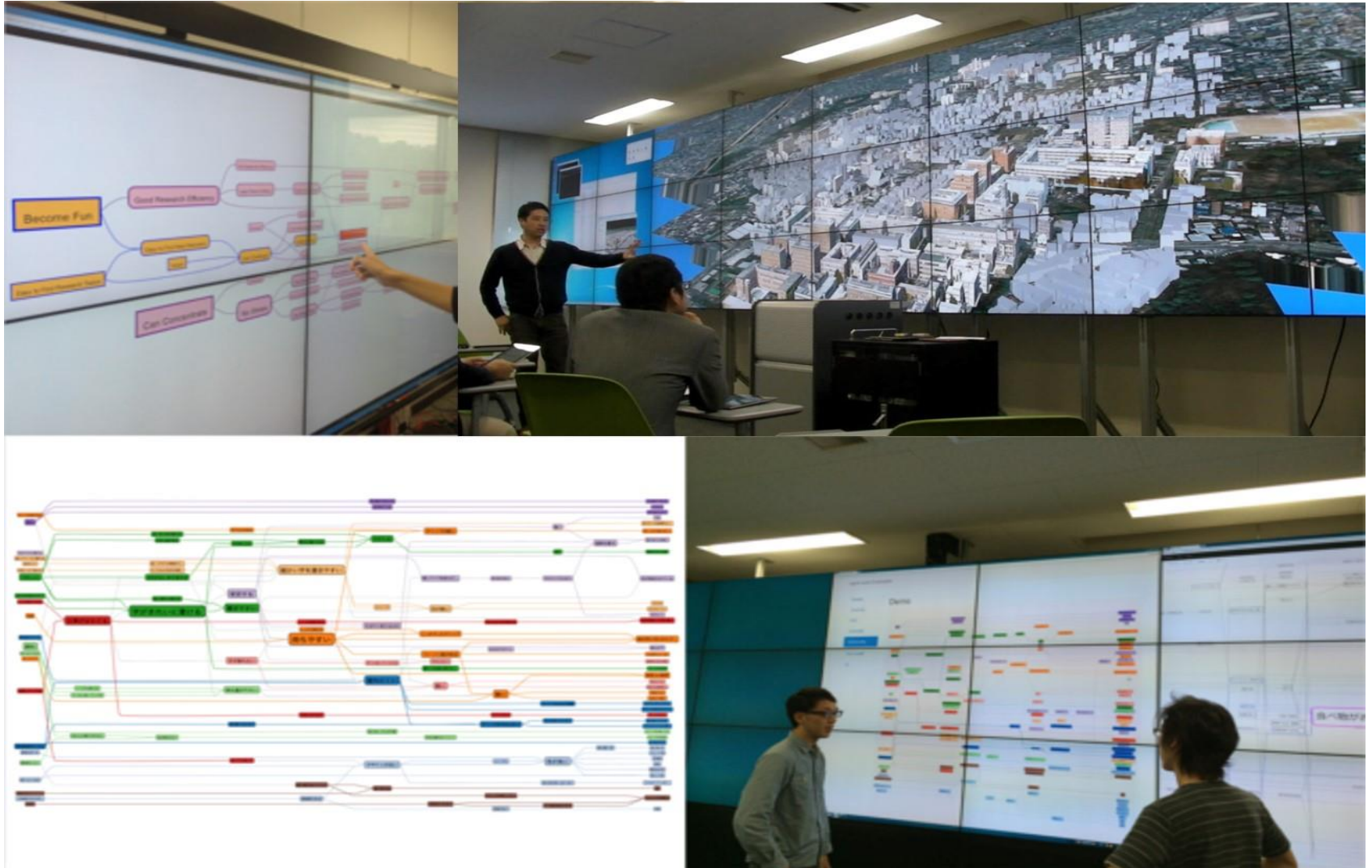
Causality in cognitive science

RQ: Why are some visualization techniques informative ?



Junichiro Sanui, 1996, Visualization of users requirements: Introduction of the Evaluation Grid Method. Proceedings of the 3rd Design amp; Decision Support Systems in Architecture amp; Urban Planning Conference, Vol.1, pp.365-374.

Visual mastermind exploration of cognitive structure



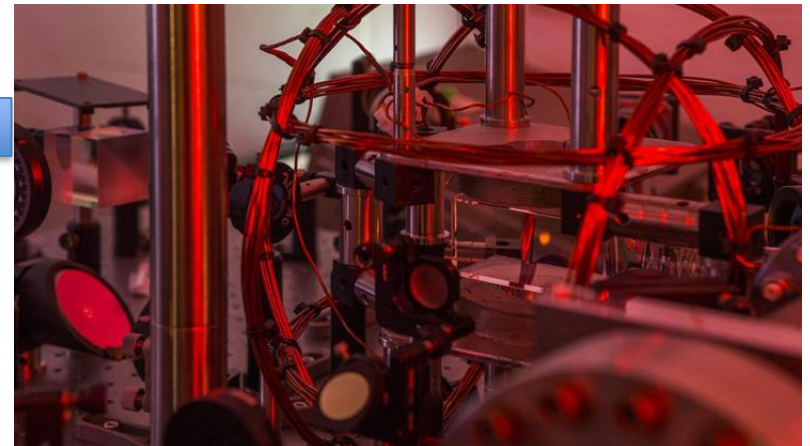
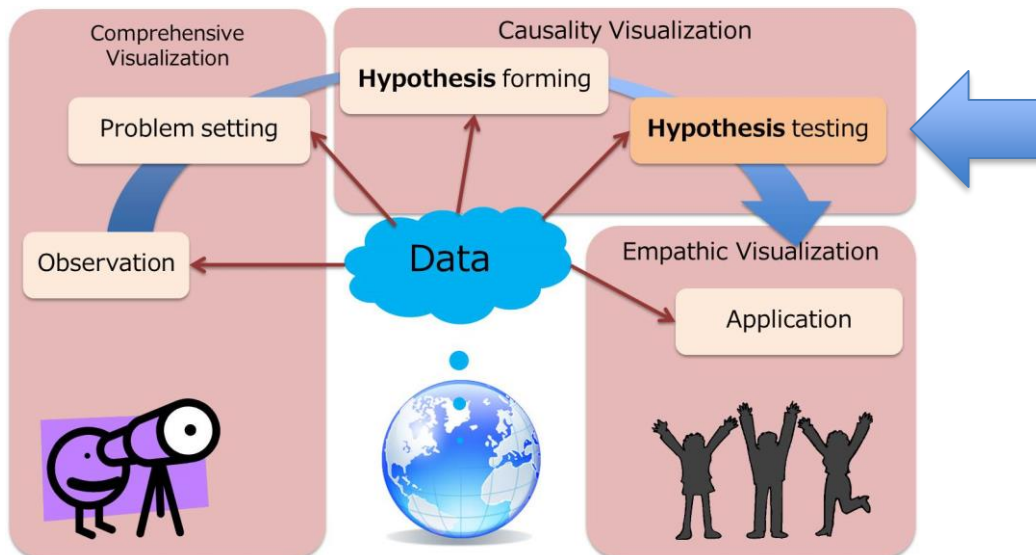
Visual Causality Exploration and its applications

SCIENTIFIC METHOD AND ARTIFICIAL INTELLIGENCE

AI in the Scientific Method ?

<https://techcrunch.com/2016/05/16/ai-learns-and-recreates-nobel-winning-physics-experiment/>

- Human asks the research question and forms the hypothesis
- AI helps human to test the hypothesis based on the Nobel-winning physics experiment



Lowering in the age of learning the Scientific Method

https://www.youtube.com/watch?v=KIFz_-KzURY

Scientific Method Song Video



Make an observation



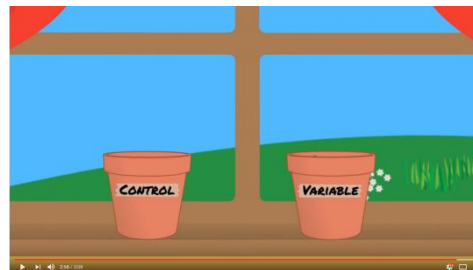
Ask a question



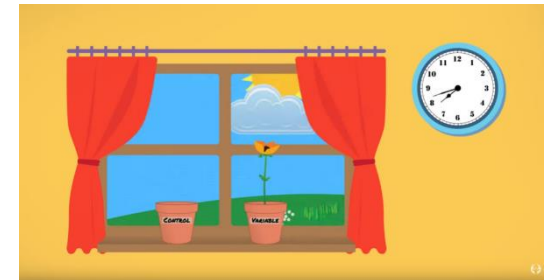
Form a hypothesis



Make a prediction

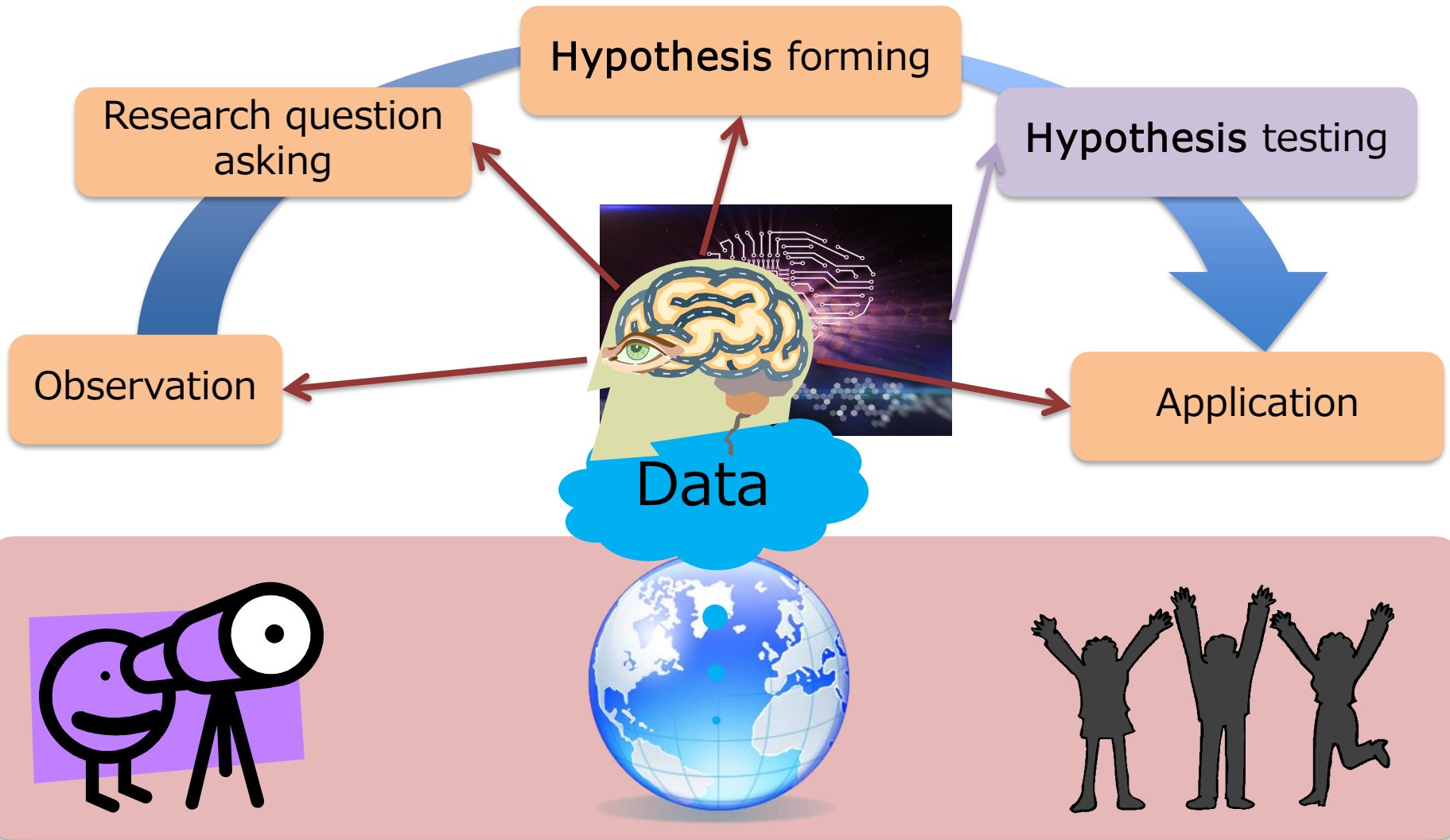


Do a test or
experimentation



Analyze data and
draw a conclusion

Scientific Discovery with AI



Summary

- Does visualization contribute to scientific discovery?
 - Yes, if it comes with the visual causality exploration.
- For such an exploration, we should
 - Design visualization techniques to facilitate
 - Interactive exploring a latent factor
 - Interactive forming and testing a hypothesis
 - Conduct the scientific method in corporation with AI
 - Lead the research question asking and the hypothesis forming
 - Collaborate with AI for the hypothesis testing