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To Restrict or Tolerate Variety of Systems: Functional Analysis of Law of Requisite Variety Based on FRAM

Takayuki Hirose
Hideki Nomoto
Yasutaka Michiura
Shota Iino

IV&V Research Laboratory
Japan Manned Space Systems Corporation

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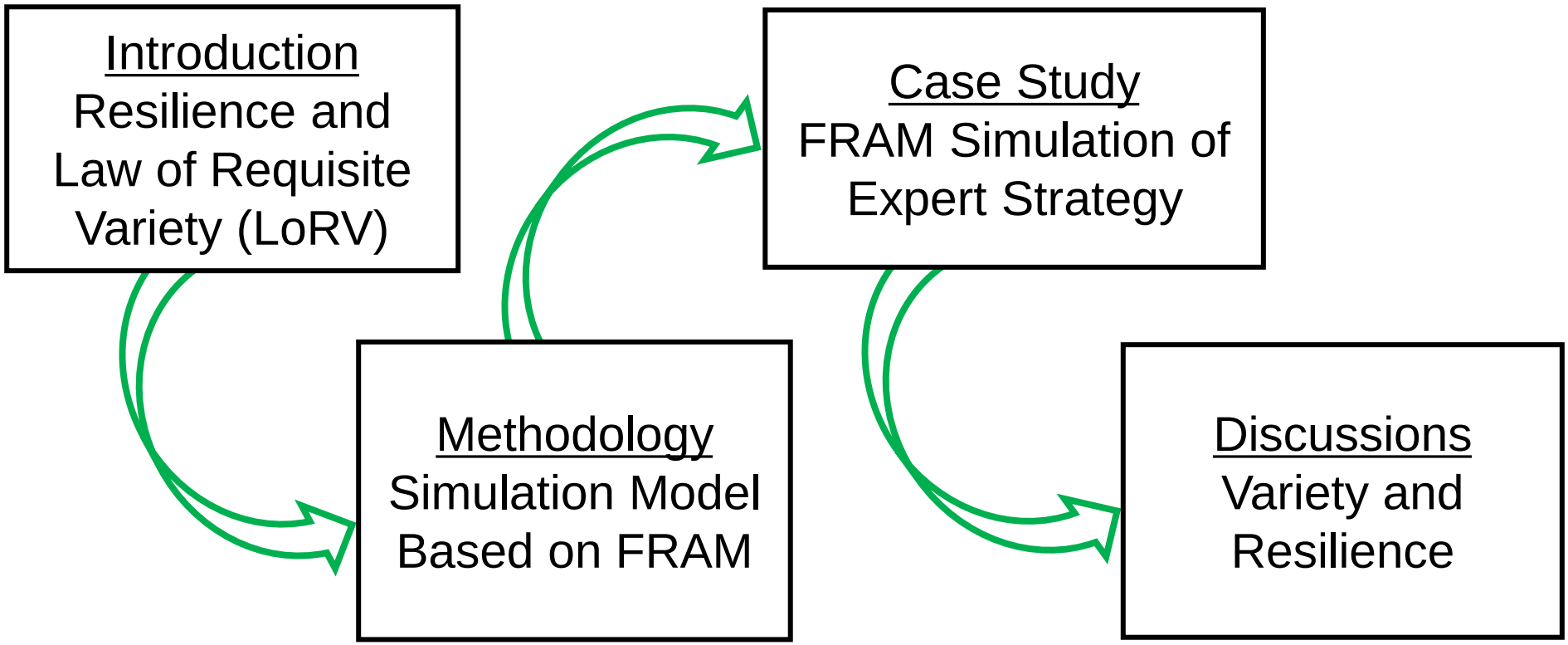
To Restrict or Tolerate Variety of Systems: Functional Analysis of Law of Requisite Variety Based on FRAM

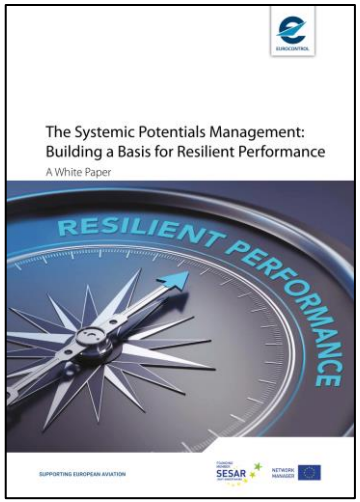


Resilience Engineering

- Developed to seek for
  - ✓ How something work in real fields of practice
    - ➢ “Why they work well” rather than “why they fail”
  - ✓ How to enhance the resilience of socio-technical systems in ever-changing situations and overcome adversities

Resilience [Hollnagel, 2021]

The ability to succeed under varying conditions,
so that the number of intended and acceptable outcomes
(in other words, everyday activities that go well) is as high as possible



- The need to understand how something works is “one of the really fundamental laws of **cybernetics**”
  - ➢ Formulated in Cybernetics, known as **Law of Requisite Variety**

Law of Requisite Variety (LoRV) [Ashby, 1957]

$$Min\big(V(O)\big) = VD - VR,$$

where $V(O)$: Variety of outcomes; VD: Variety of Disturbances; VR: Variety of Responses

Two options to minimize the variety of outcomes/uncertainties: $V(O)$

- **Decrease** the variety of disturbances: VD
  (e.g., Restricting human, organization, or systems by rules to standardize their performance)
  - **Not realistic** since $VD \cong \infty$
- **Increase** the variety of responses: VR
  (e.g., accepting "flexibility" of human, organization, or systems and utilizing them)
  - **only feasible option** to overcome the uncertainties

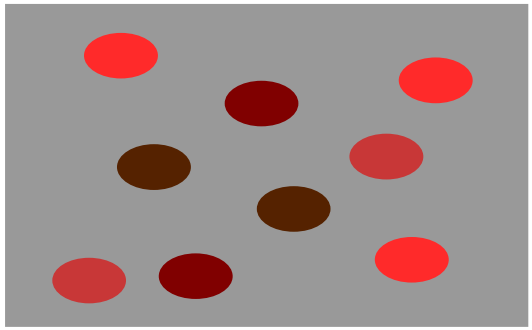
⇩ in Resilience Engineering

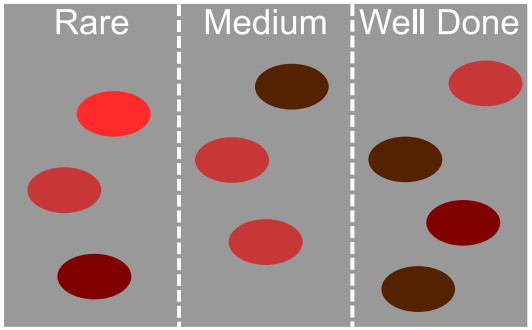
- Increasing the variety of regulators/responses is important
  - Investigated
    - ✓**how to confirm/show the effect of VR**
    - ✓**why it is important in Resilience Engineering**

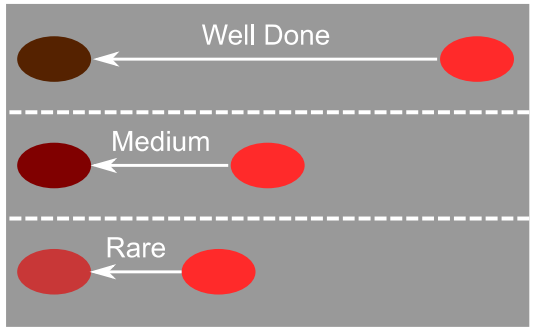
Example: Strategy of Expert Chefs

Research conducted by Alex Kirlik (1998)

- Discussion about how skills of experts are performed
  - Focused on skills to see hidden essential parameters through visible parameters and physical activities
- Observation at a restaurant, confirmed 3 characteristic strategies of chefs
  - Suggested the effectiveness of such strategies **based on LoRV**
    - ✓ generating a novel source of perceptual information
    - ✓ assisting sophisticated functional modeling of the task environment



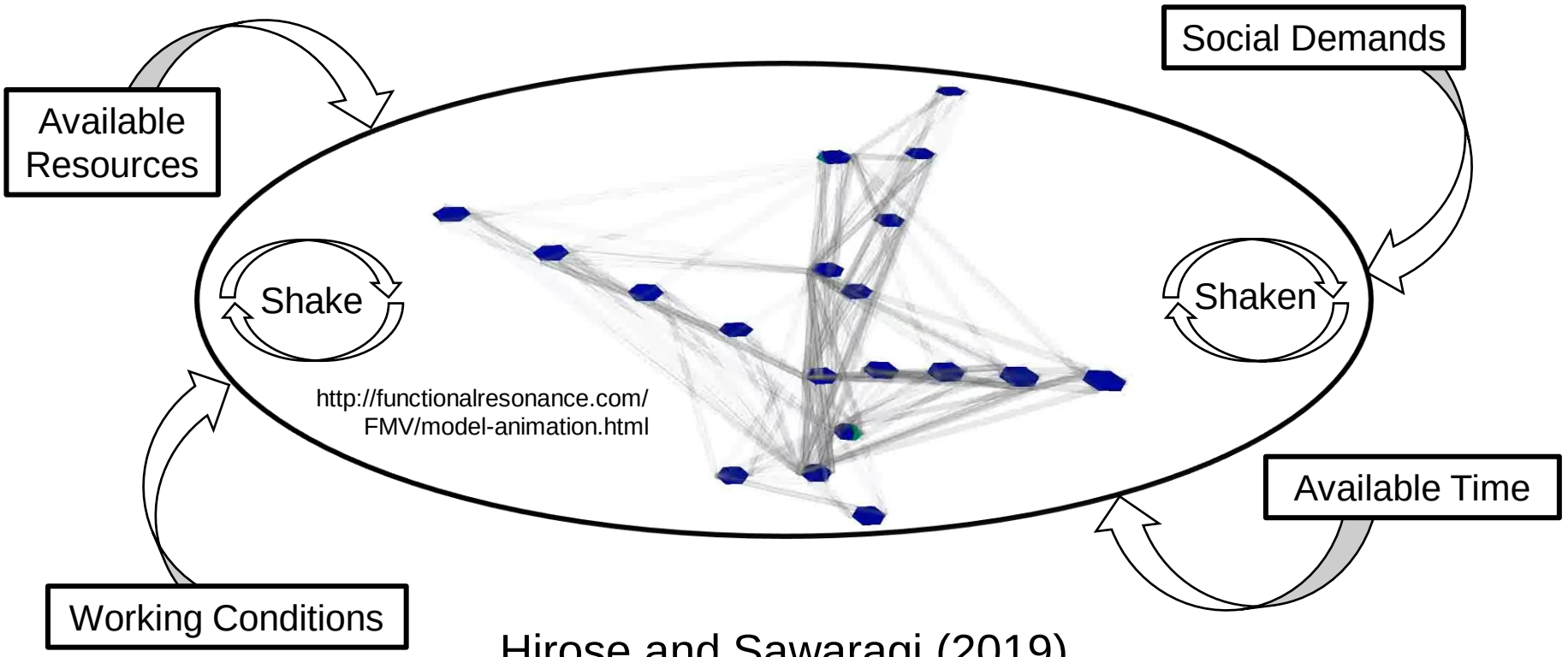




To step into more and investigate

Functional behavior of each strategy from Resilience Eng. perspective

Simulation model of FRAM



Hirose and Sawaragi (2019)

IFAC-PapersOnLine Volume 52, Issue 19, 2019, Pages 13-18.

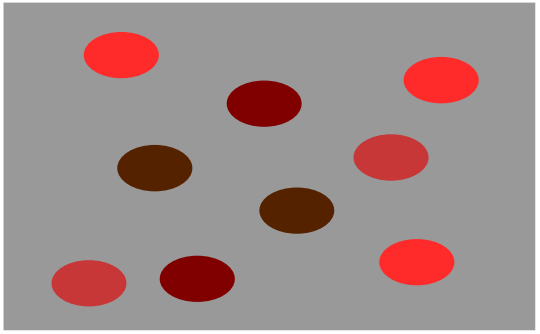
Variability of environment/functions were defined with 2nd generation HRA

- ✓ Working environment variability: Change of **11 CPC scores**
  - ➢ **Initial Trigger (Input)** to "shake" functions
- ✓ Function variability: Dynamic transition of **Control Mode** in each function
  - ➢ **Primary Result (output)** of simulation

Strategy of Expert Chef [Alex Kirlik (1998)]

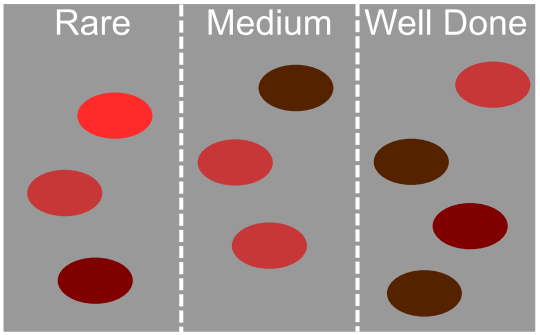
Brute Force

1. Put raw meats randomly on the grill, according to the orders
2. Memorize the goal states of each steak
3. Manage the steak conditions simultaneously



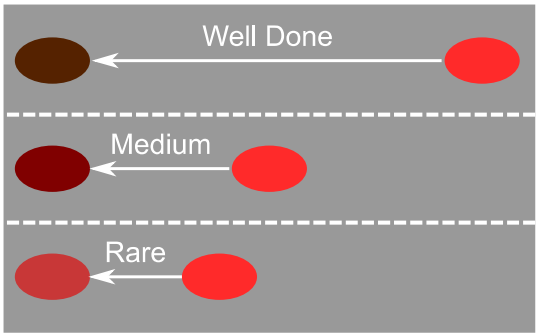
Position Control

1. Separate region on the grill vertically, according to the goal state of steaks
2. Manage the steak conditions simultaneously



Position + Velocity Control

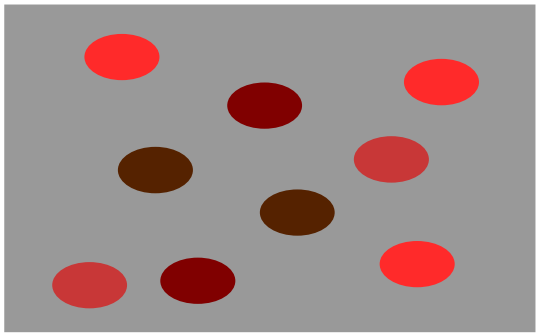
1. Separate the region on the grill horizontally
2. Decide initial position, according to the goal state
3. Move/Flip all of them at constant speed/intervals
4. Pickup steaks arriving at the left edge of the grill

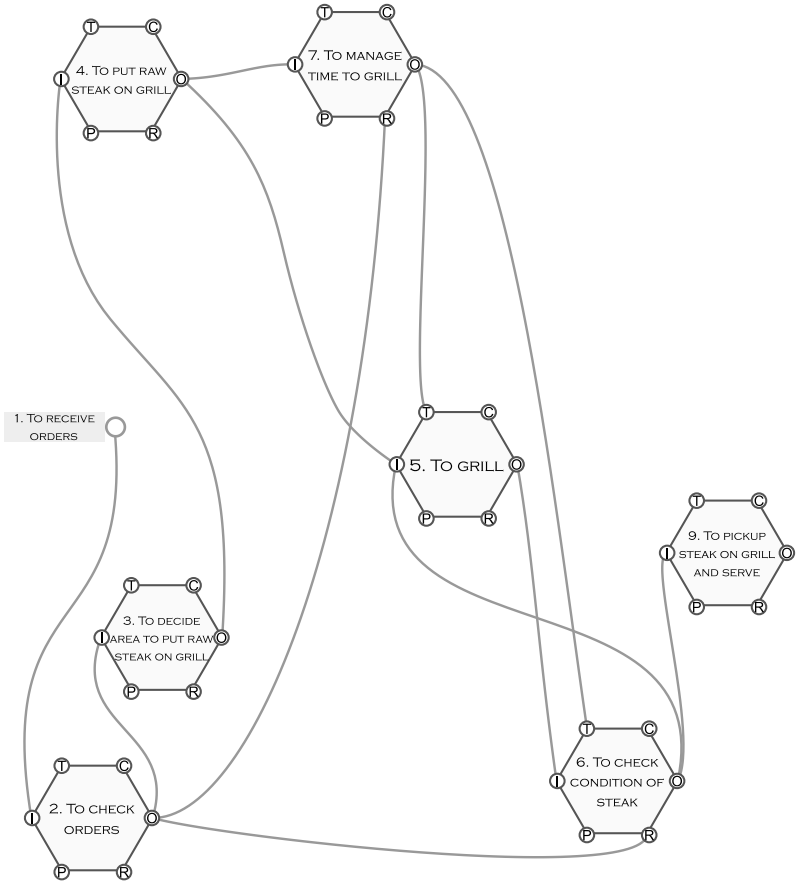


FRAM Representation: Brute Force

- The most basic structure of all strategies
  - Consisting of the following basic functions/connections

1. To receive orders
2. To check orders
3. To decide area to put on the grill
4. To put meats on the grill
5. To grill
6. To check condition of steak
7. To manage time to grill
8. To pickup steak and serve

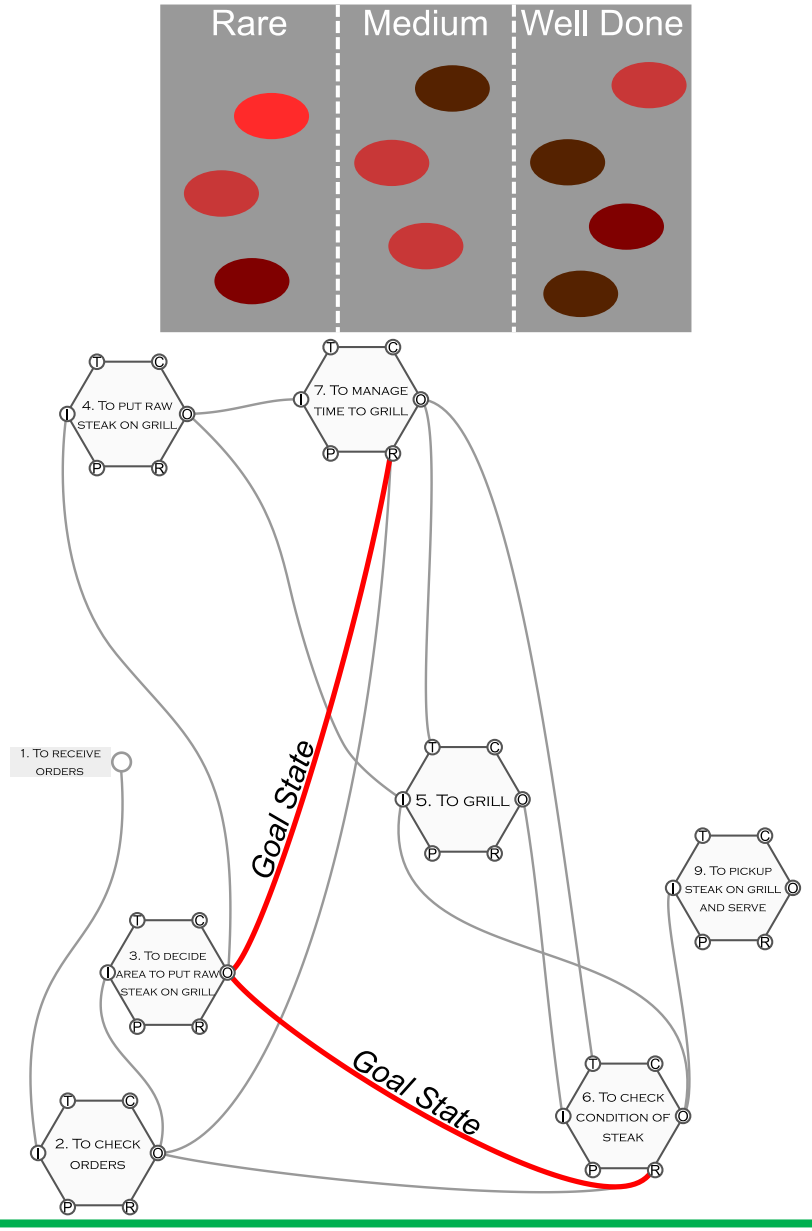




https://doi.org/10.1016/j.ifacol.2022.10.231

FRAM Representation: Position

- The basic structure is same as the case of Brute Force strategy
- Additional connections representing
  - Location of meats provides information about goal state
  - used in the function of
    - ✓ Time management
    - ✓ Current status check



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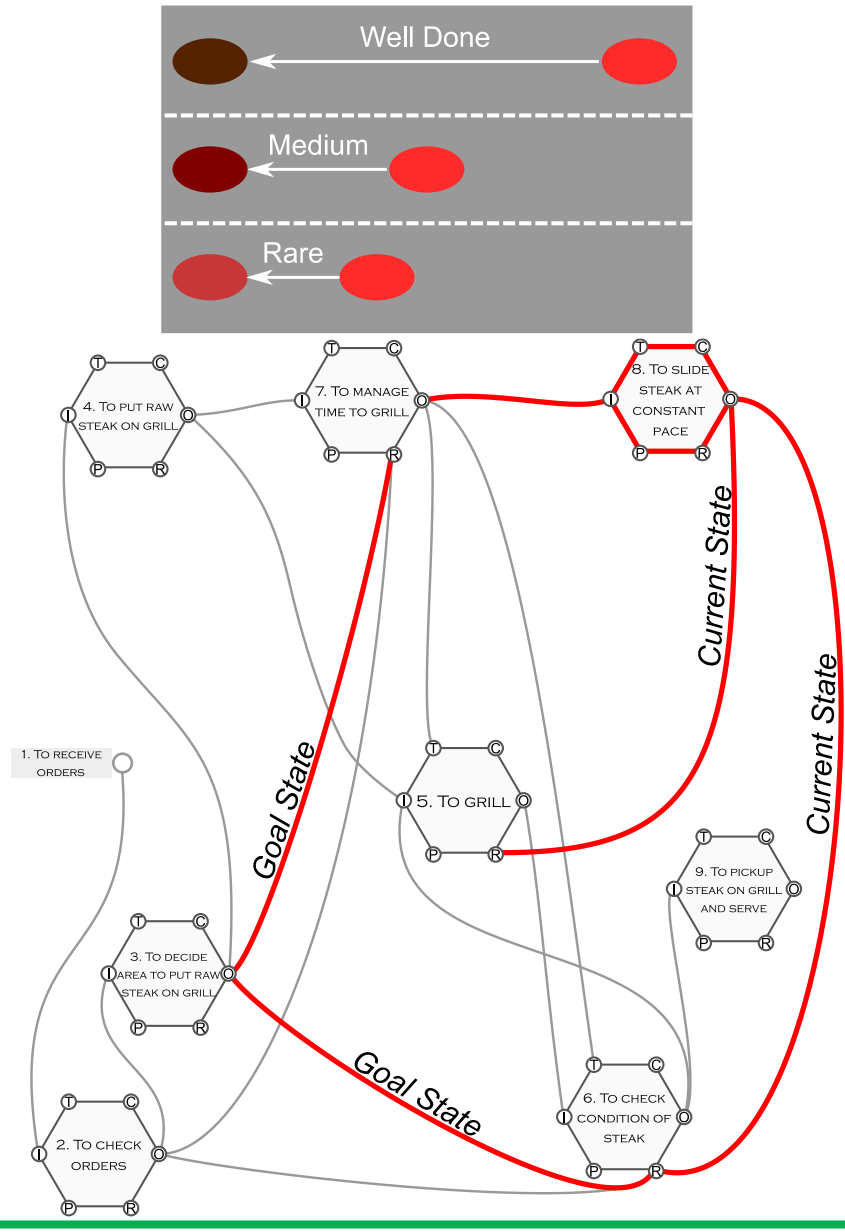
FRAM Representation: Pos + Vel

- The basic structure is same as the case of Pos strategy
- Additional function representing
  - Flip/Move at constant speed/intervals
  - Providing information about current status of steaks as resource of the following function
    - ✓ Grilling
    - ✓ Current status check



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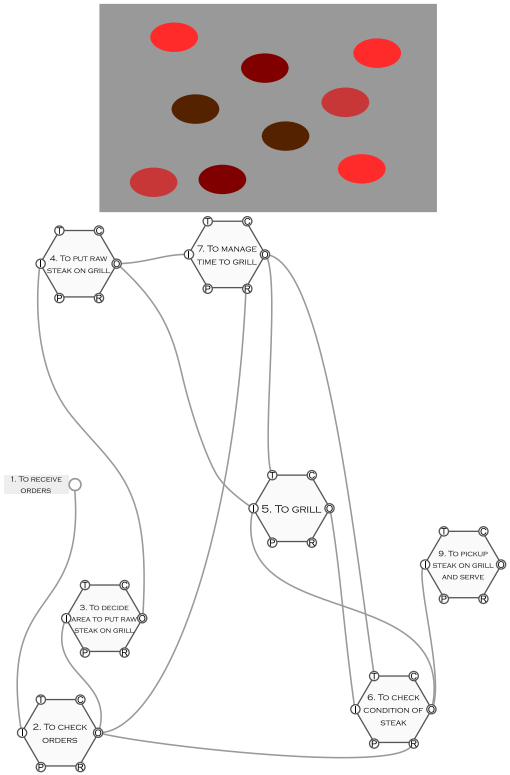
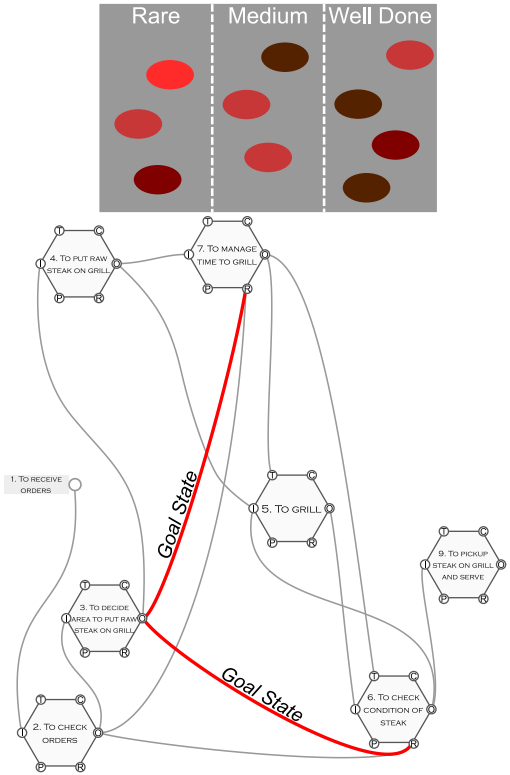
FRAM Simulation of Strategies

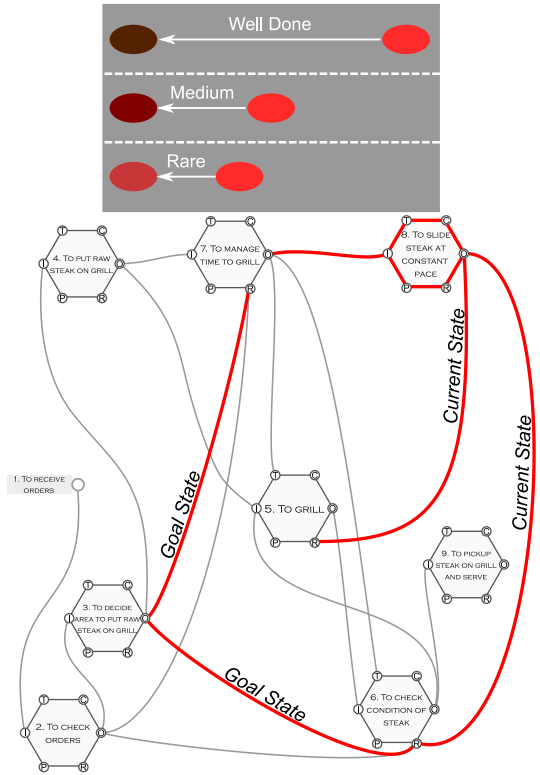
Brute Force



Position



Position + Velocity



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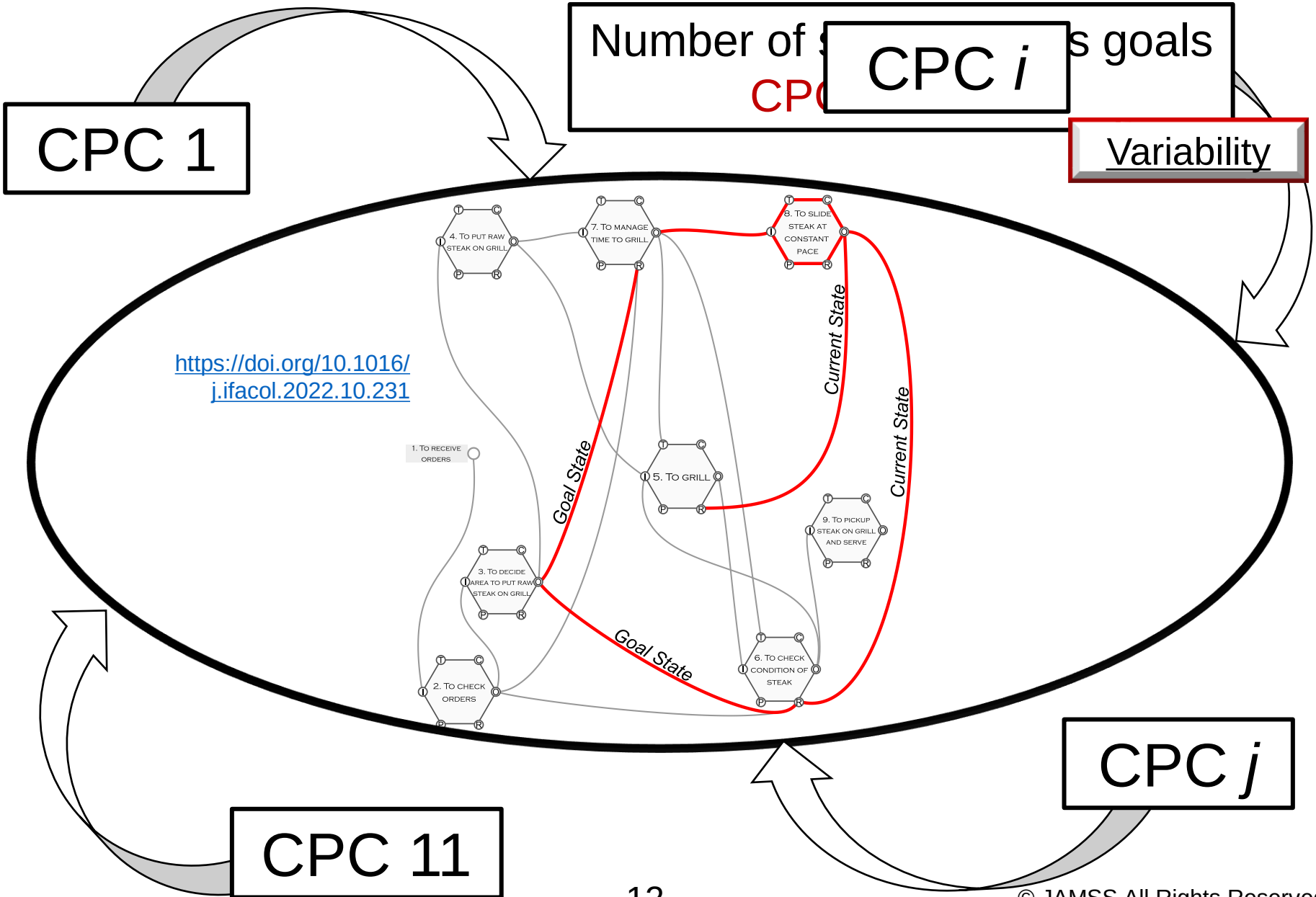
With setting sensitivity of functions against change of CPC scores

"Shake" FRAM Networks of each strategy

Generating Variability to Run FRAM Simulation

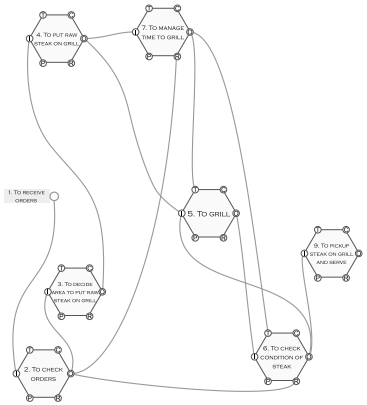


Simulation Result

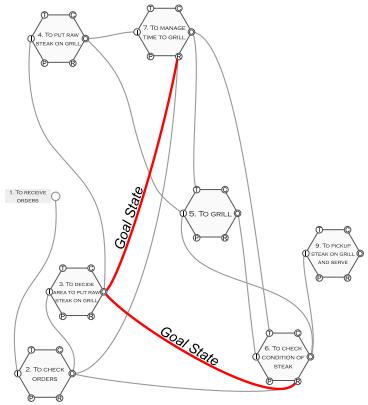
Chaos/ Panic

Order

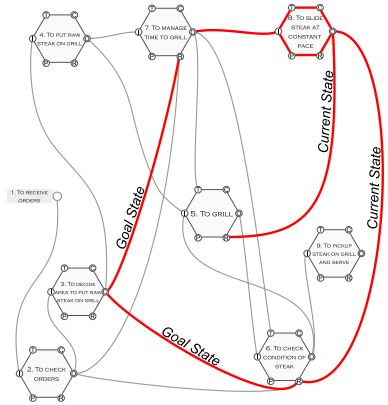
Brute Force

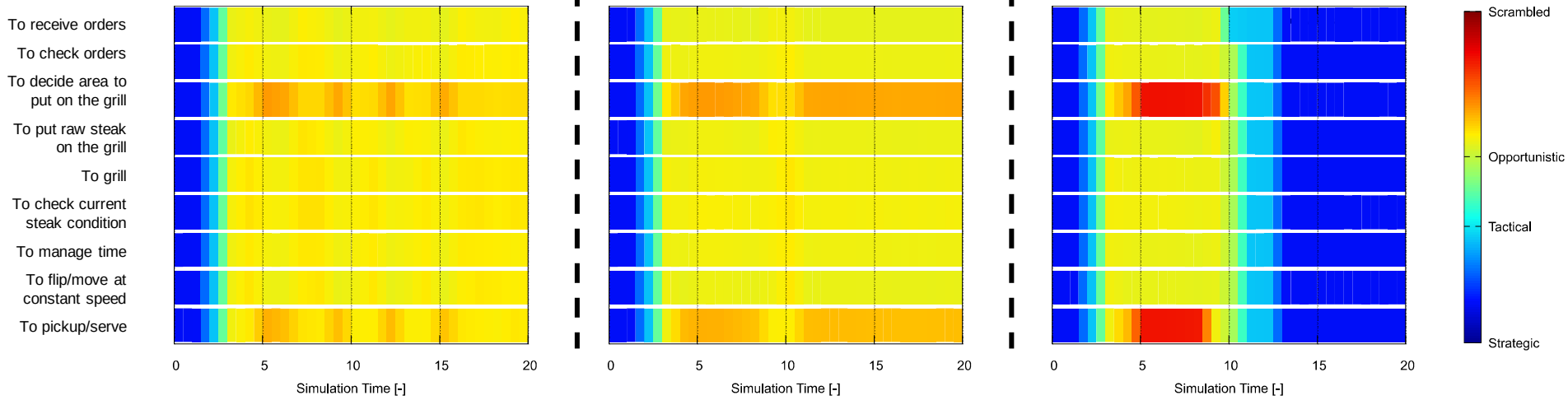


Position



Position + Velocity





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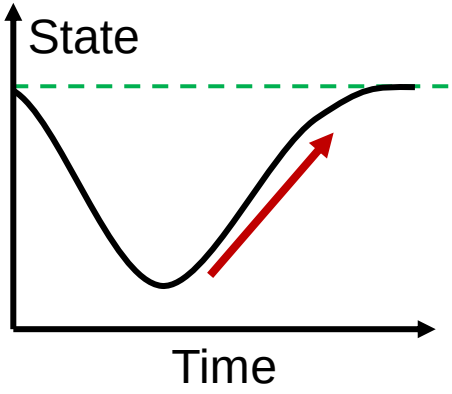
- Brute Force/Pos → Not recovered from the effect of variability (Not Resilient)
- Pos+Vel → Recovered from the effect of variability (Resilient)
  - Additional connections/function worked as if it were a “shock-absorber”

The Word: Resilience

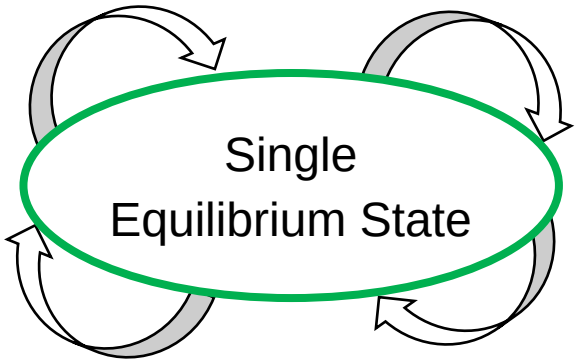
- According to a dictionary, “Resilience” is
  1. The ability to become recovered, happy, or prosperous again after a difficult situation or event
  2. The ability of a substance such as rubber to return to its original shape after it has been deformed or bent



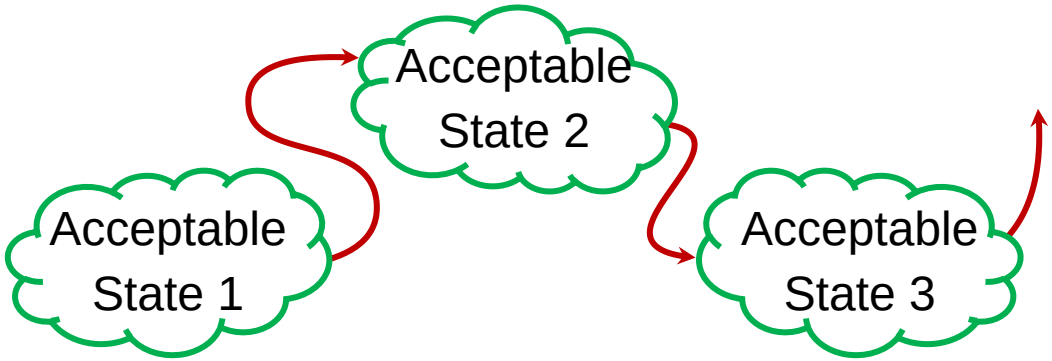
Resilience of Ecosystems (Holling, 1973)

- Defined two properties of ecosystem to describe their behavior:
  1. Stability: ability to return to an equilibrium state after a disturbance
  2. Resilience: **ability to overcome changes/disturbances and survive**
     - **Evolution of systems to move forward with variabilities**

Stability



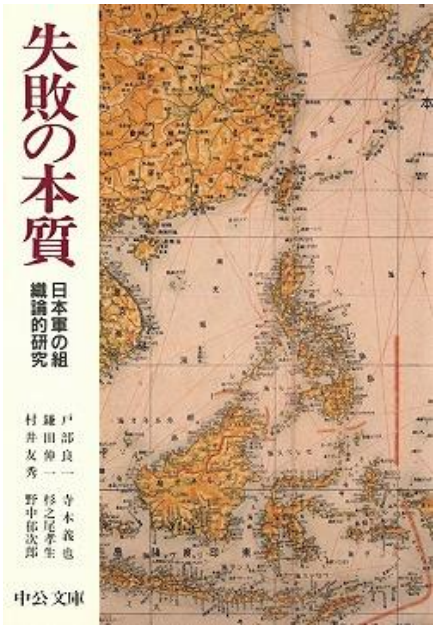
Resilience



Variety, Variability, and Adaptability

Book: Shippai no Honshitsu (The Nature of Failure, 1984)

- Discussing why old Japanese military lost in WW2 in terms of organizational theory
- One of the primary reasons was **loss of adaptabilities** caused by **excessive adaptations to past successes** (Theory of evolution says adaptation precludes adaptability)
  - Adaptive systems requires some degrees of instability to avoid excessive stability
  - Excessively stable systems can be tough against specific conditions but vulnerable to the changes
    - Terminal state of systems already “dead”



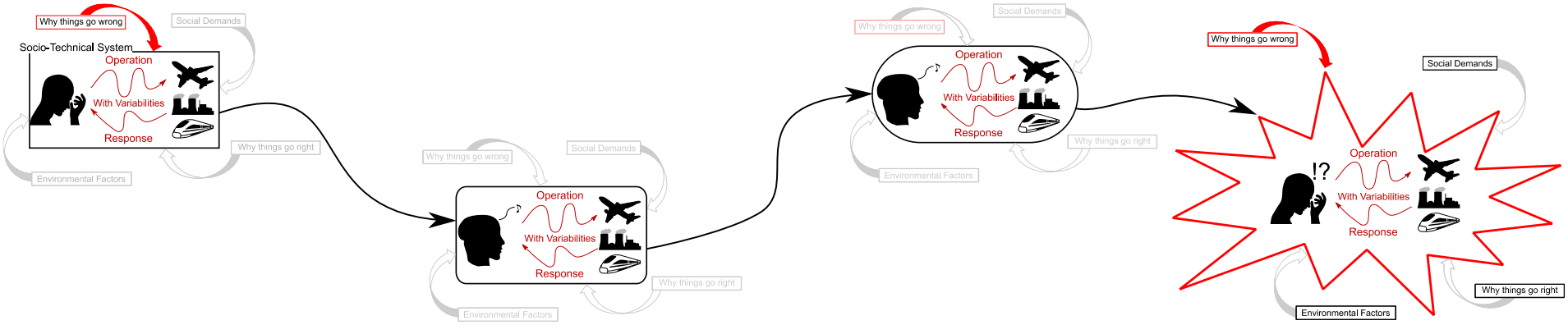
https://www.chuko.co.jp/bunko/1991/08/201833.html

Adaptive (Resilient) Systems

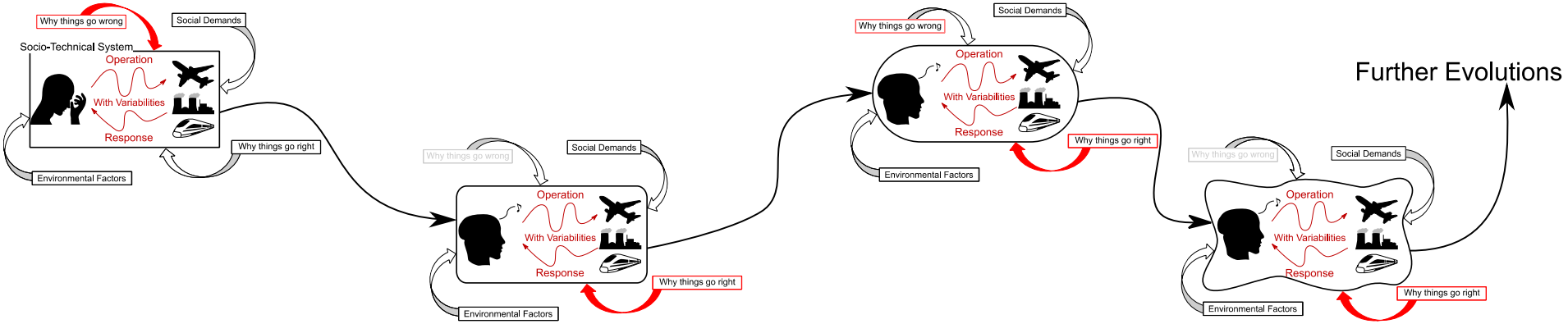
- Instability/Variability shall exist in an adaptive system
  - Variety of systems’ elements is essential for their adaptabilities

Safety-II Providing Feedback

- Safety-I make systems very tough against specific conditions **but exhaust**
  - **Feedbacks** about the safety measures in “safe” world w/o any dangers
  - **Adaptabilities** to their surrounding environment (**Loss of Resilience**)

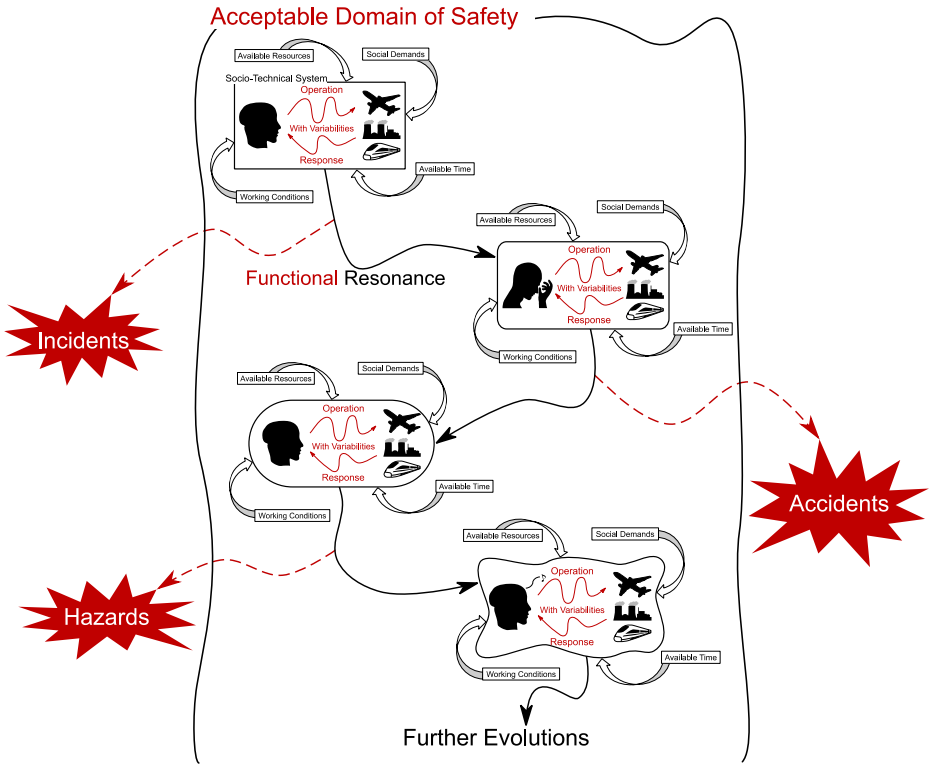


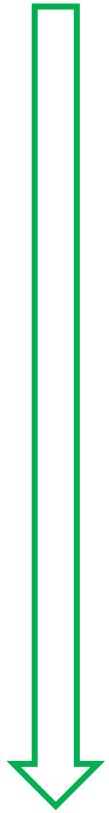
- Safety-II provides feedback from every possible resources, **enabling**
  - **Communication** with the surrounding environment (**Learning**)
  - **Evolution** into more resilient systems to survive in ever-changing environment



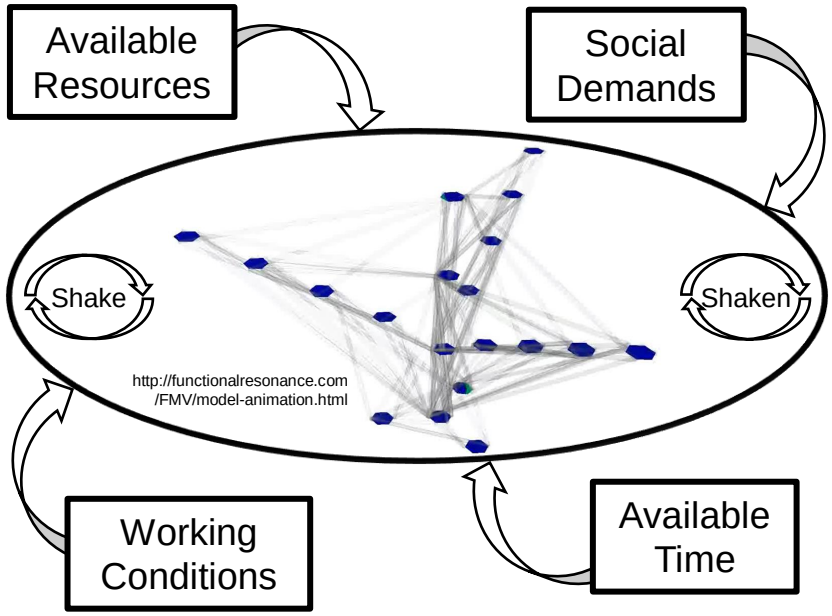
Variety, Variability, and Resilience

- Variety inside systems provides necessary variabilities for resilience
  - But could also bring about negative/intractable consequences (cf. The Equivalence of Success and Failure Principle)
- We need to **envision the evolution** of those systems
  - FRAM analysis in this perspective is expected





Envisioning



Hirose and Sawaragi (2019)
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Summary

- Resilience Engineering has been attracting its attention, seeking
  - "Why things go right" rather than "why things go wrong"
  - How to enhance the resilience of socio-technical systems in ever-changing environment and overcome adversities
- Law of Requisite Variety (LoRV) plays an important role in the RE
  - Increasing the variety of responses is the only feasible option to cope with infinite disturbances/uncertainties
- Case study: "Strategy of expert chefs" was examined
  - FRAM simulation of 3 strategies observed by Alex Kirlik (1998)
    - Confirmed that a strategy requiring the most action variety was the most resilient against the variability of working environment
- Adaptive systems require unstable conditions
  - Necessary to involve variety inside the systems and integrate them
    - Impact on resilience should be envisioned with FRAM

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