Technische Hochschule Nürnberg

ANTIFRAGILITY
gain from uncertainty

http://antifragility.science/

Antifragile feedback control from biological to technical systems

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Applied Antifragility Group

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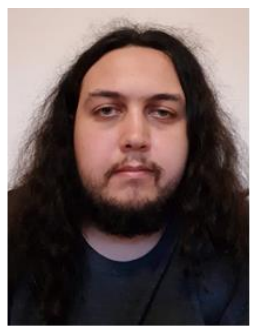
Jeffrey West

SPICES Lab

ohm Technische Hochschule Nürnberg



Ertan Halilov
SHK

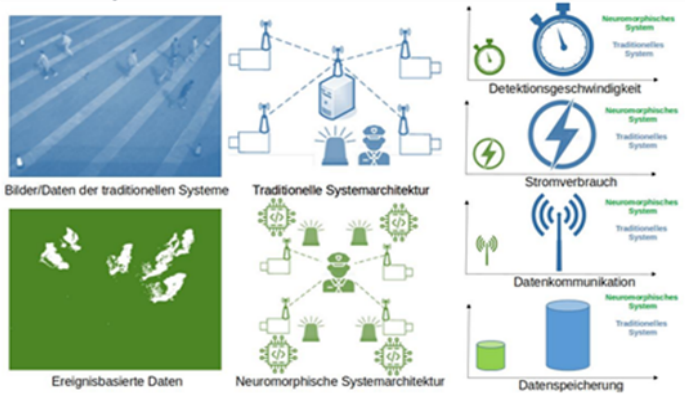
Julian Main
SHK

David Weiss
SHK

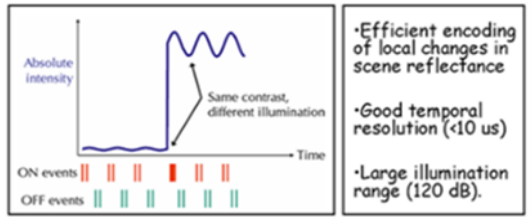
Daniel Pommer
WissMit/
Doktorand

Cristian Axenie

Fast, Efficient, Robust and Green Inference



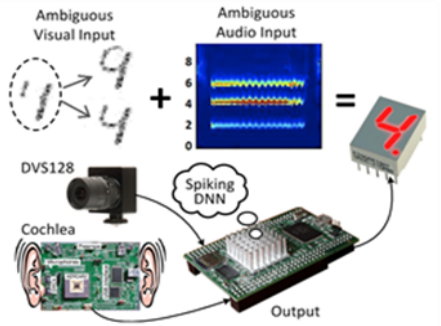
Spike-based/Event-based data representation



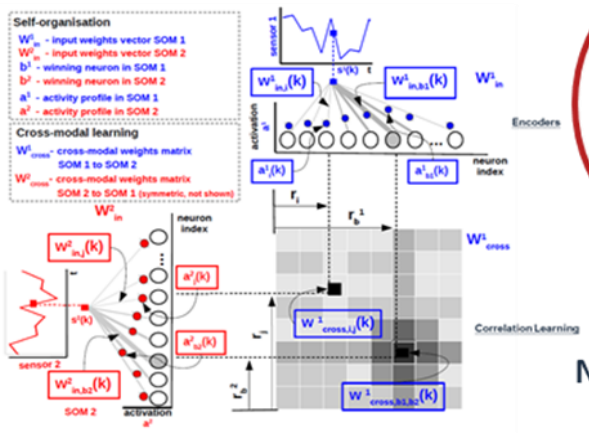
- Efficient encoding of local changes in scene reflectance
- Good temporal resolution (<10 us)
- Large illumination range (120 dB).

Efficient, Green, and Robust Low-power Inference

Sensor Fusion



Learning algorithms



Algorithms for Spiking Neural Networks

SPICES Lab
Technische Hochschule Nürnberg

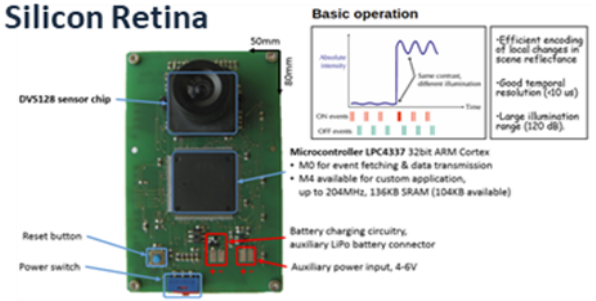
Data fusion and Closed-loop Control

Closed-loop Sensorimotor Control

Neuromorphic Chips

Neuromorphic Sensors and Computers

Silicon Retina



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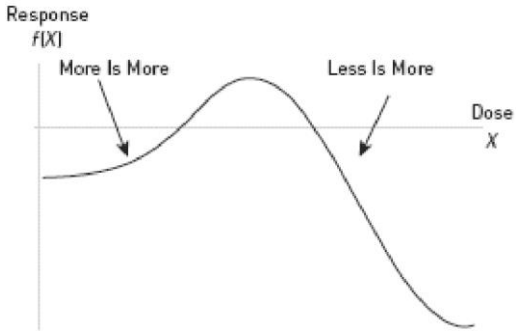
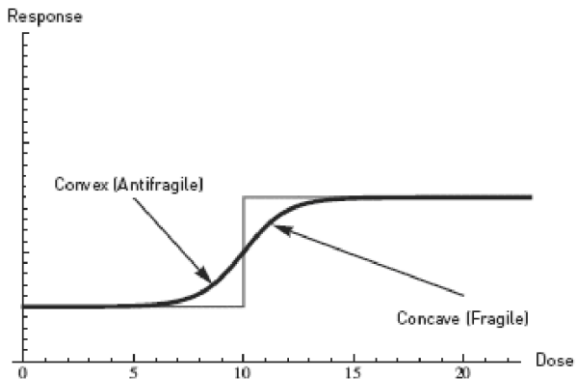
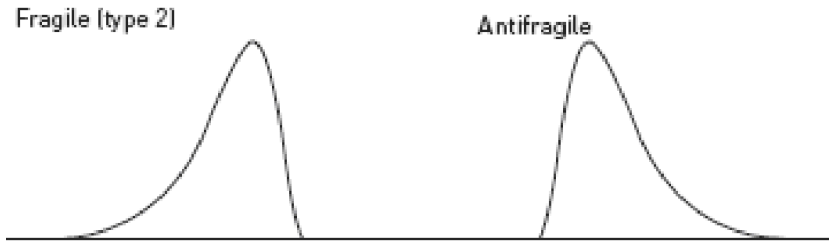
Outline

- Antifragility
- Beyond probability distributions
- Antifragile feedback control
  - Mechanistic design
  - Learning from biology
  - Transferring to technology

Antifragility

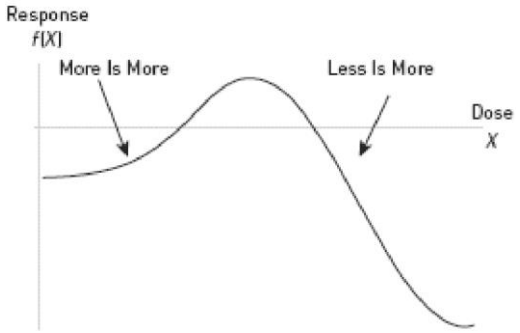


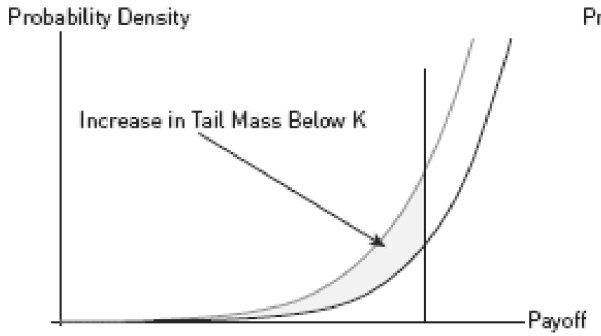


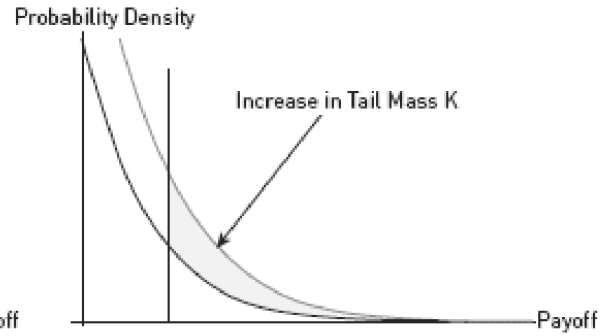


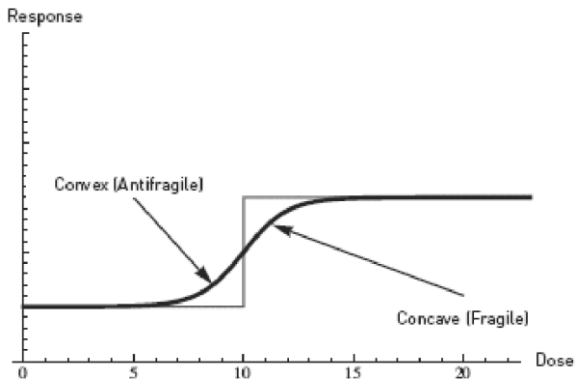
Source: Taleb, Nassim Nicholas. *Antifragile: Things that gain from disorder*. Vol. 3. Random House Trade Paperbacks, 2014.

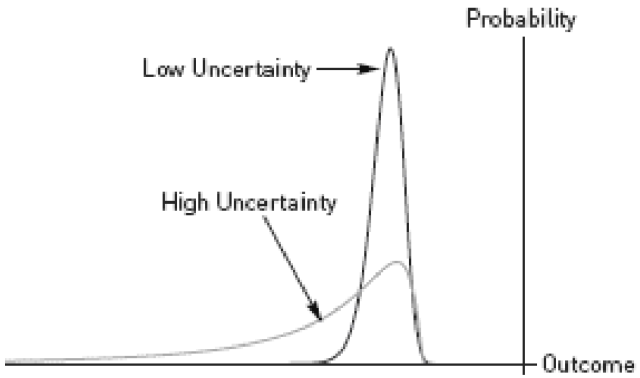
Antifragility

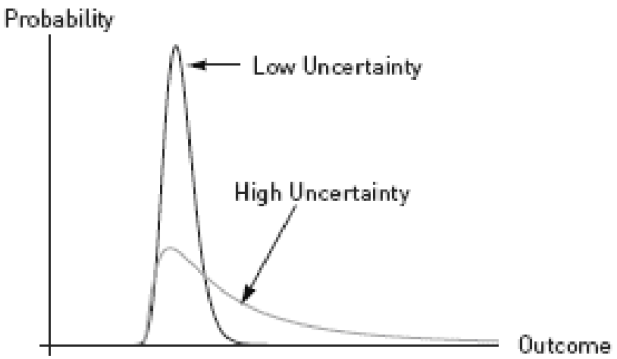








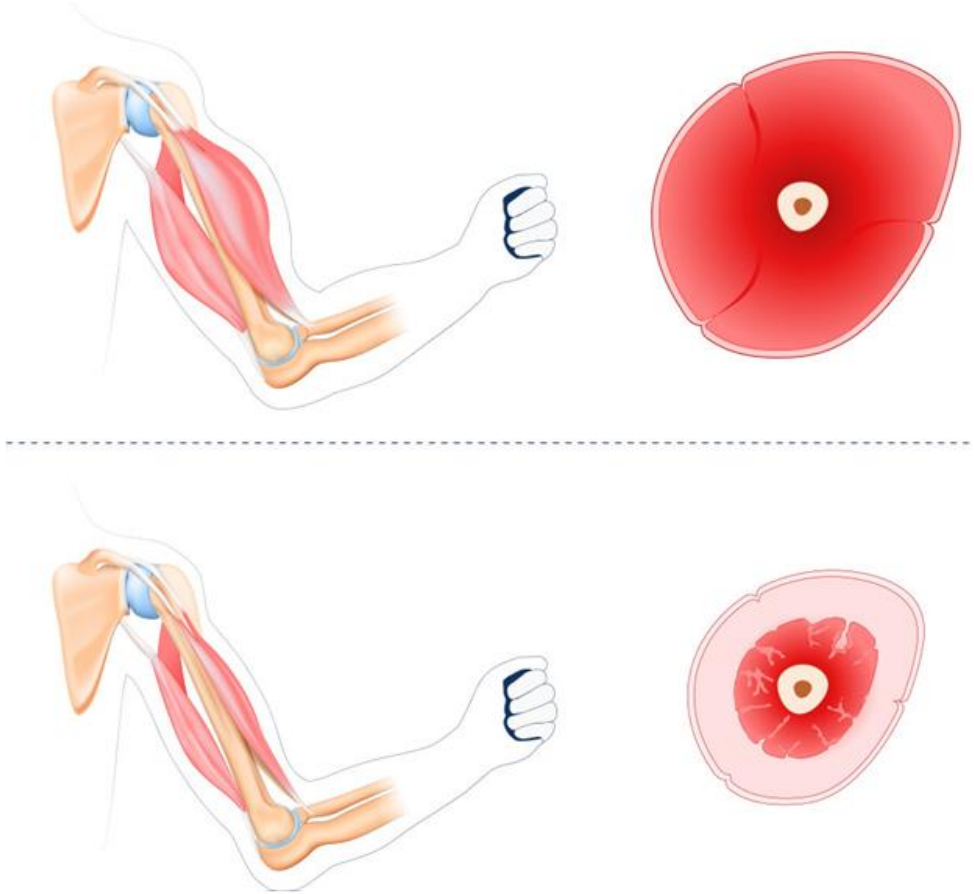




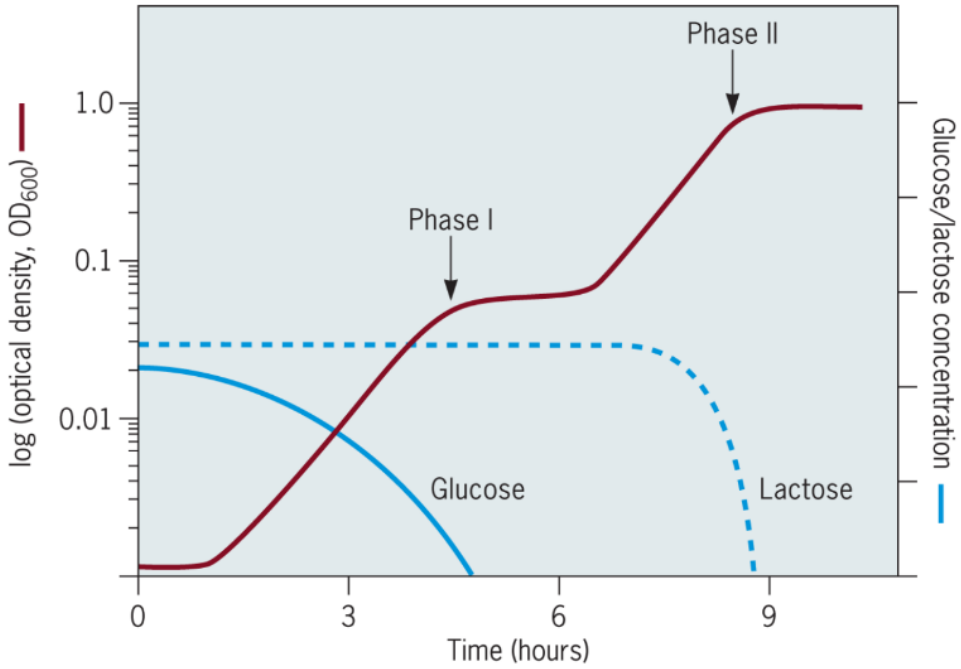
Source: Taleb, Nassim Nicholas. *Antifragile: Things that gain from disorder*. Vol. 3. Random House Trade Paperbacks, 2014.

Beyond probability distributions

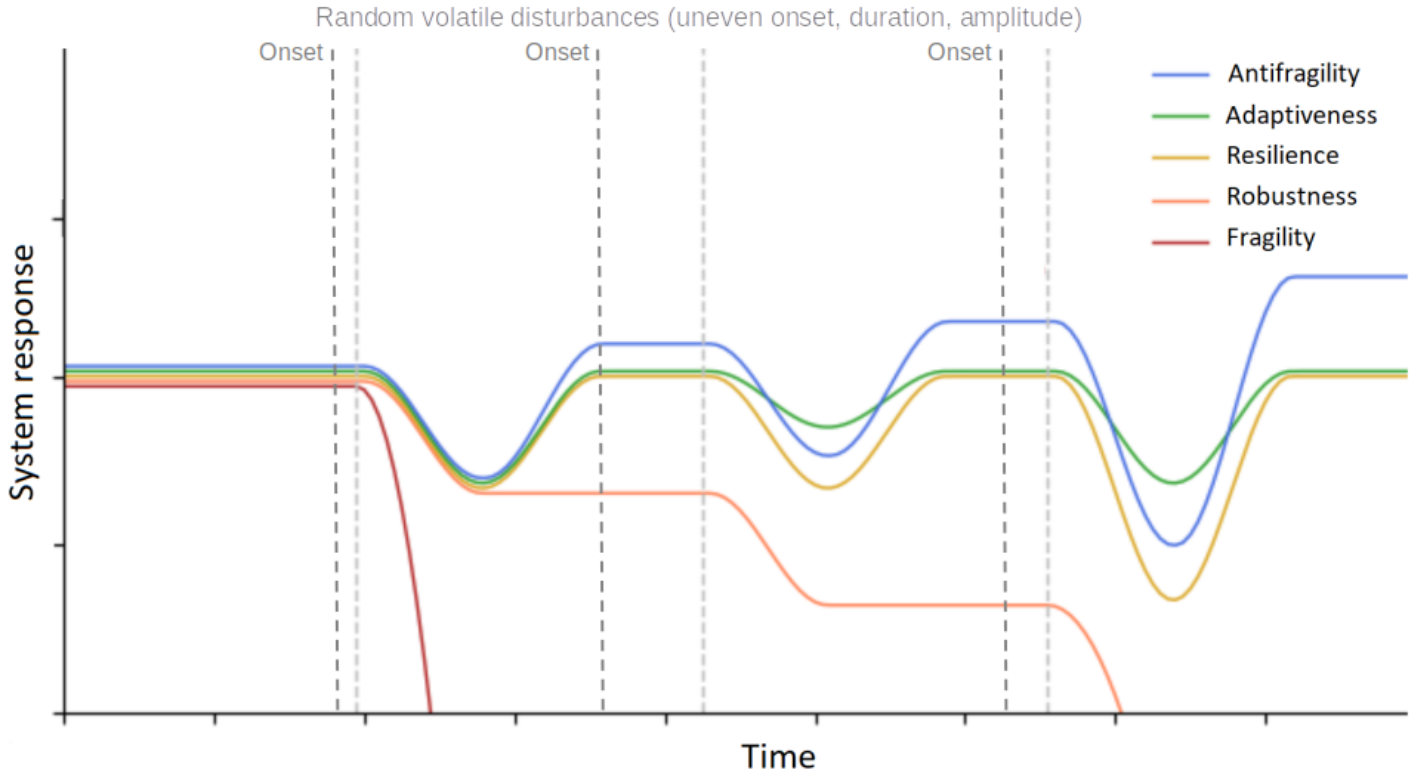
Muscle hypertrophy – atrophy



E-Coli lactose to glucose metabolic switch



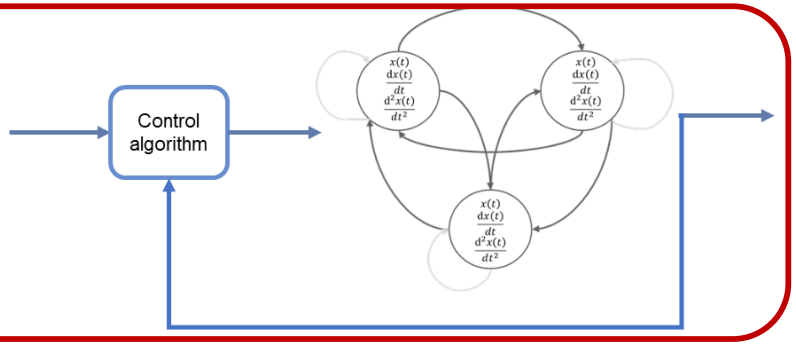
Beyond probability distributions



Beyond probability distributions

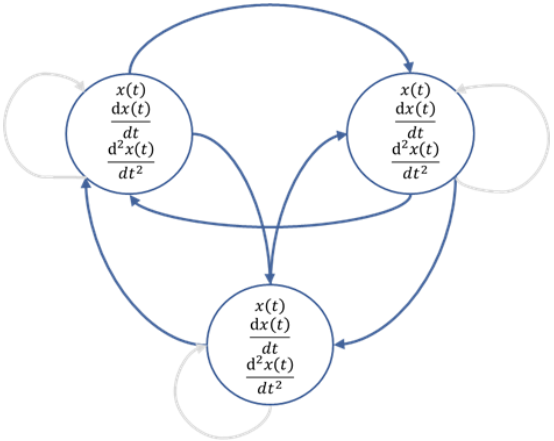
Induced/interventional antifragility

Induced and interventional antifragile systems benefit from harm derived from input distribution unevenness based on emergent system dynamics in closed-loop with a controller driving the system towards prescribed dynamics in the presence of modulated or non-stationary disturbances, noise, and volatility.



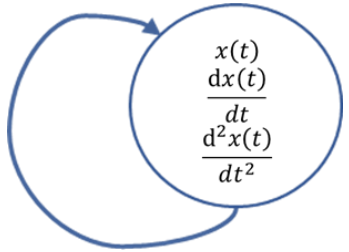
Inherited/evolutionary antifragility

Inherited and evolutionary antifragile systems benefit from harm derived from input distribution unevenness, based on the emergent system dynamics and its interactions with the operating environment (i.e. disturbances, noise, modulated perturbations).



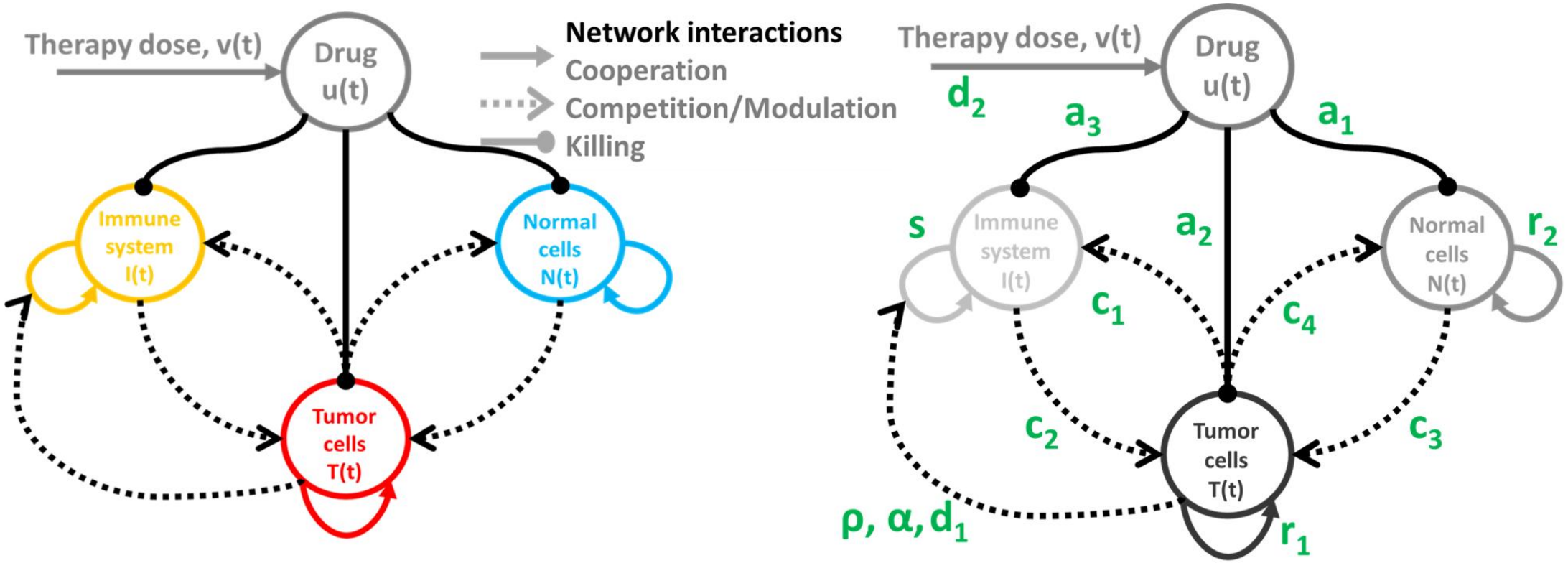
Intrinsic/ecological antifragility

Intrinsic and ecological antifragile systems benefit from harm derived from internal dynamics distribution unevenness, based on the convexity of the response function of the system without external input and solely based on the internal components' heterogeneity and resilience.



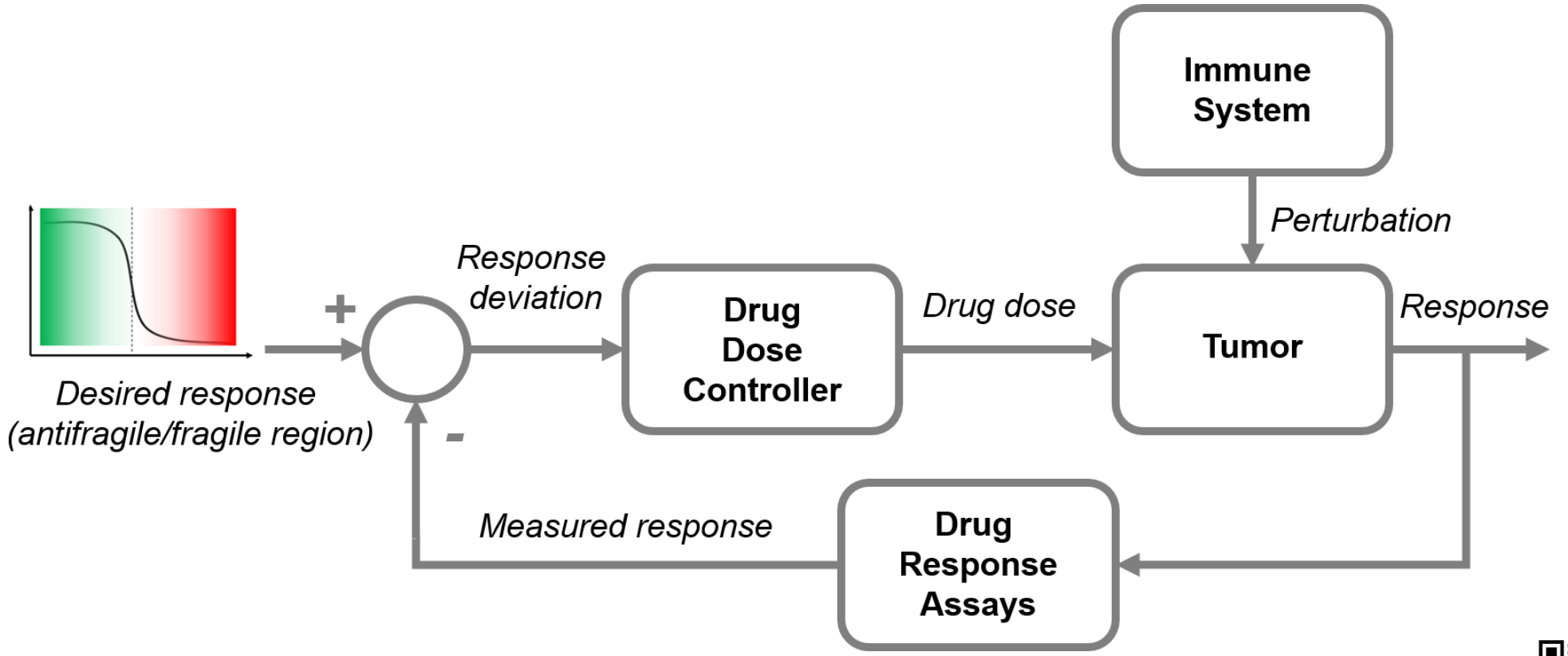
Axenie, C., Lopez-Corona, O., Makridis, M. A., Akbarzadeh, M., Saveriano, M., Stancu, A., & West, J. (2023). Antifragility as a complex system's response to perturbations, volatility, and time. *arXiv preprint arXiv:2312.13991*.

Antifragile feedback control: mechanistic design



Axenie, C.; Kurz, D.; Saveriano, M. Antifragile Control Systems: The Case of an Anti-Symmetric Network Model of the Tumor-Immune-Drug Interactions. *Symmetry* **2022**, *14*, 2034.

Antifragile feedback control: mechanistic design



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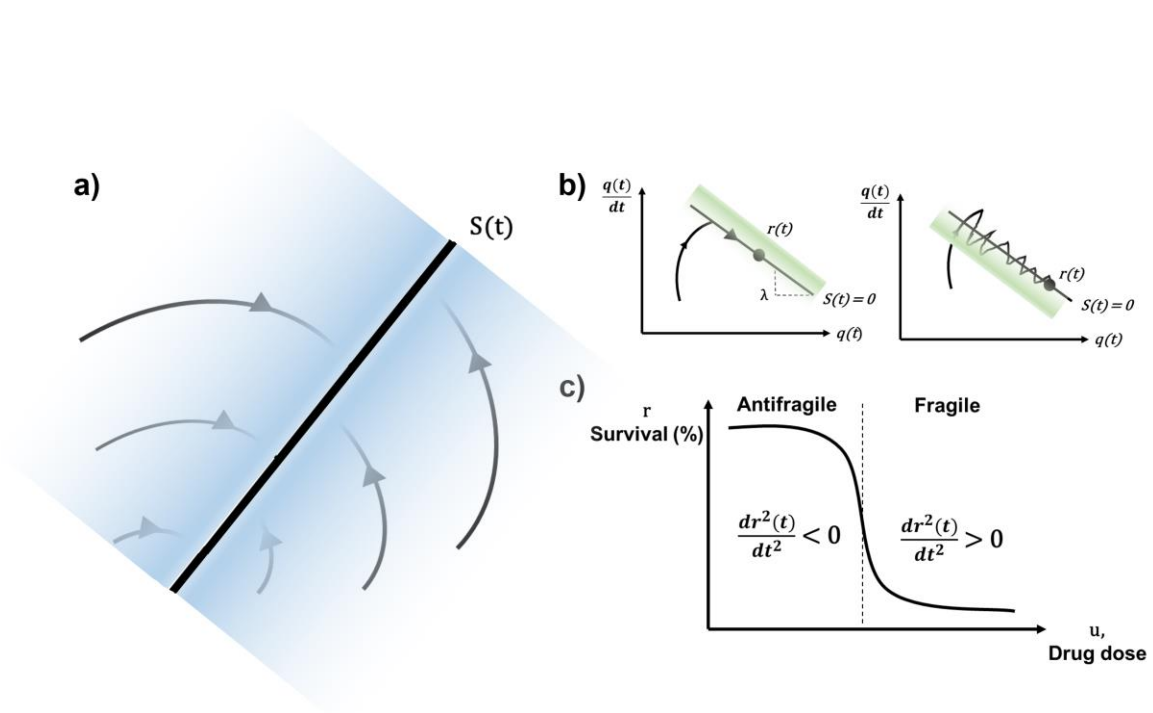

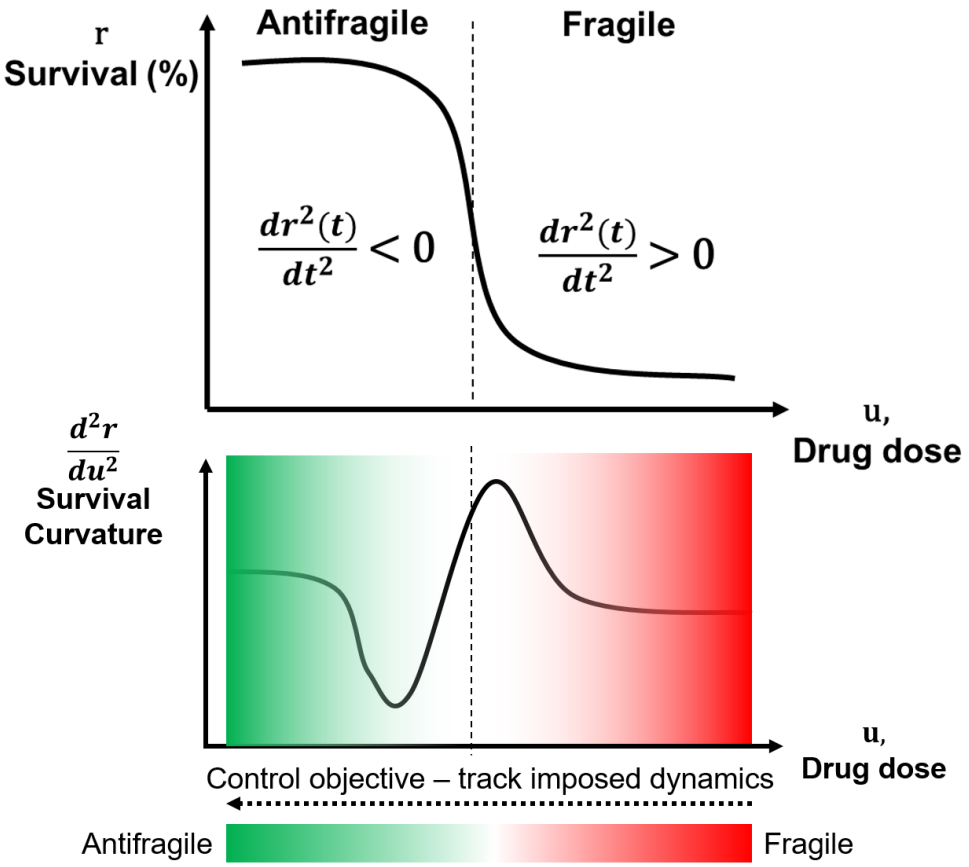

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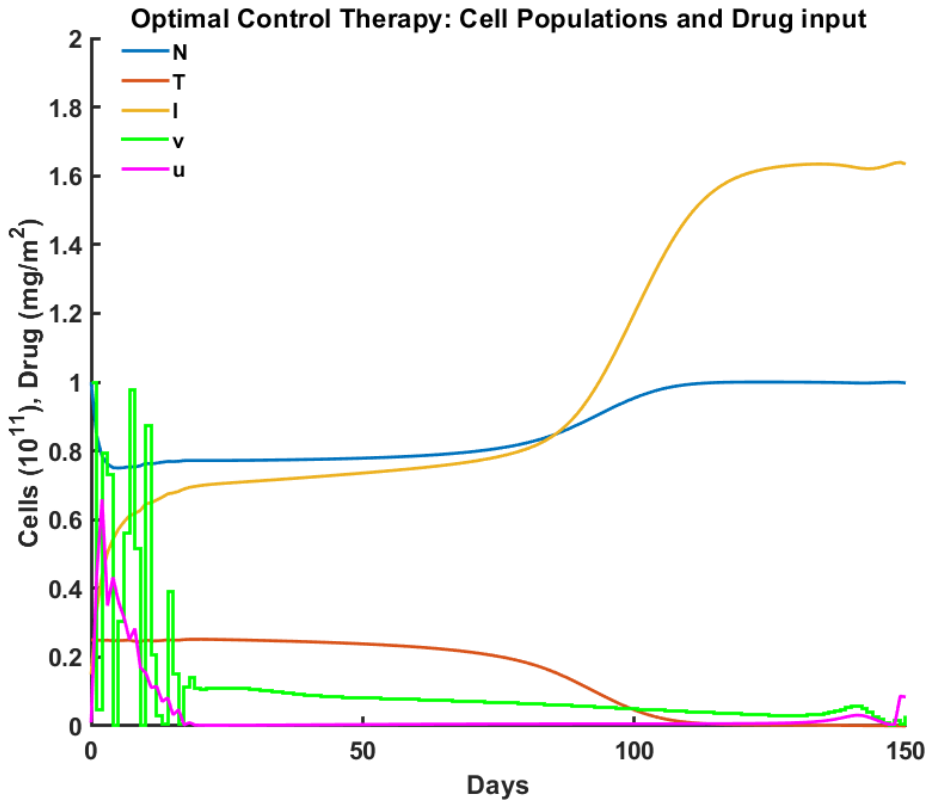

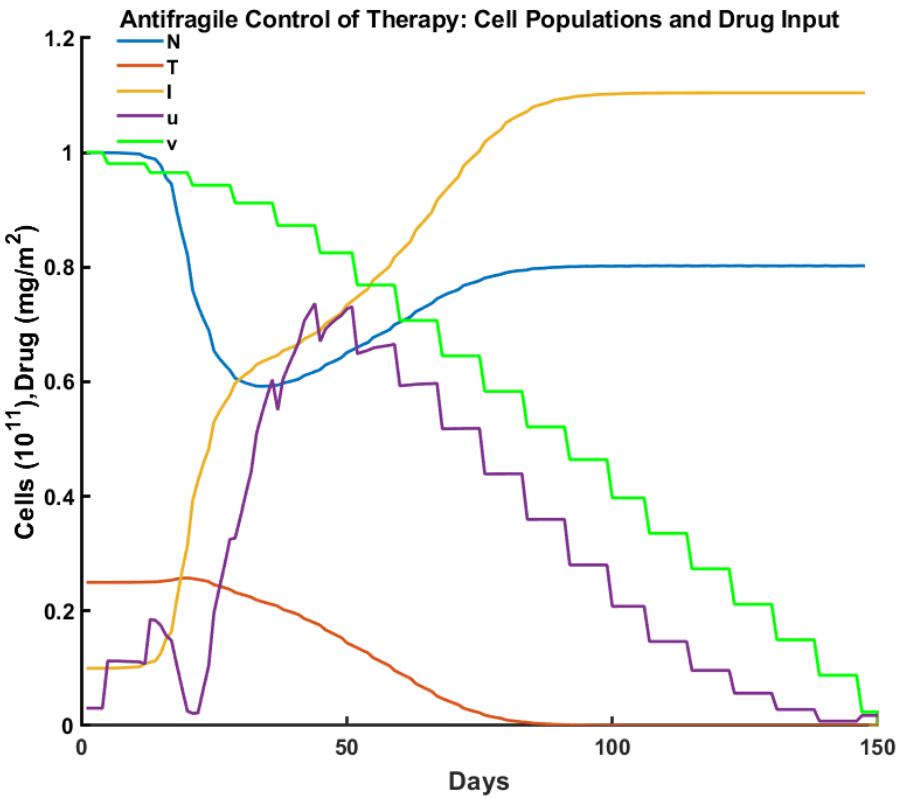

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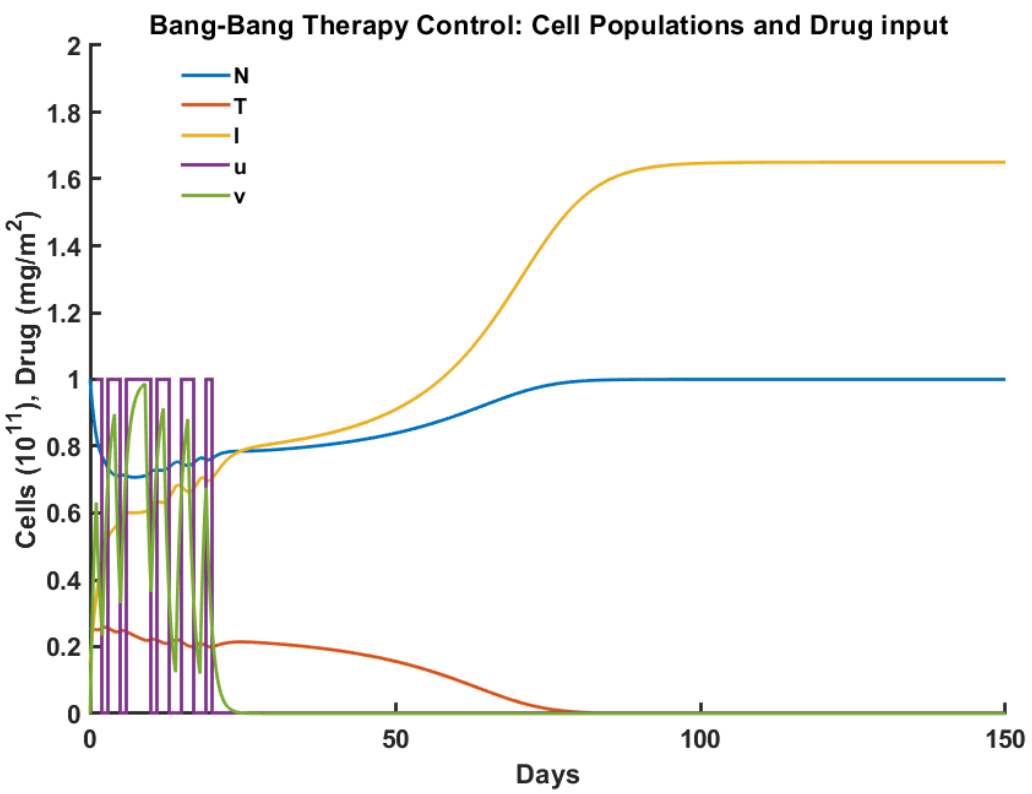
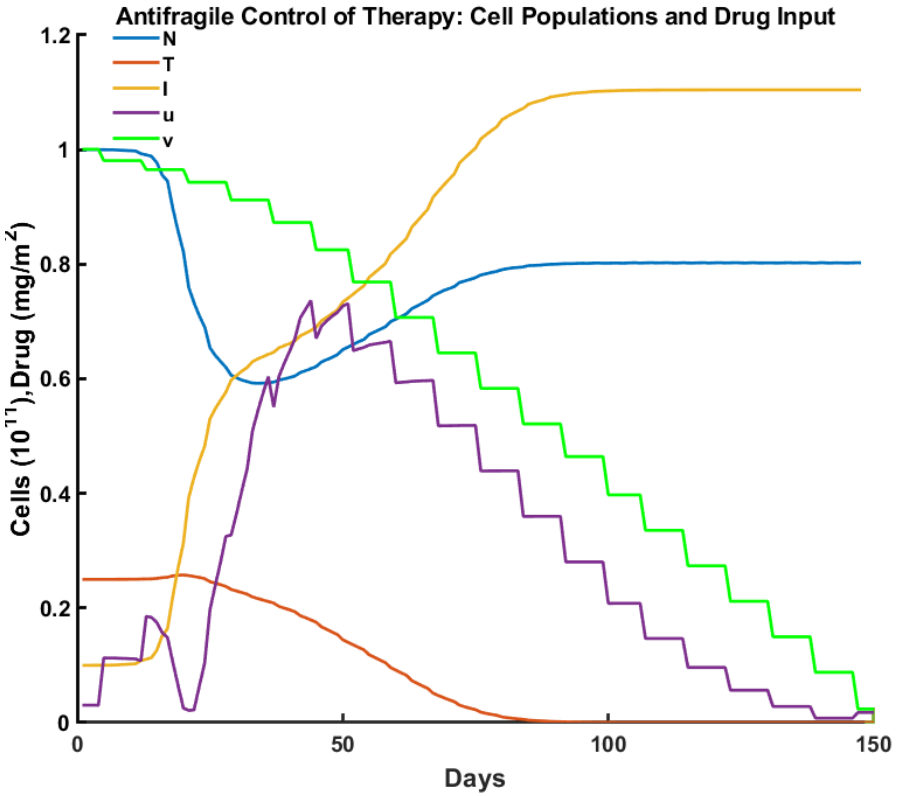
Antifragile feedback control: mechanistic design





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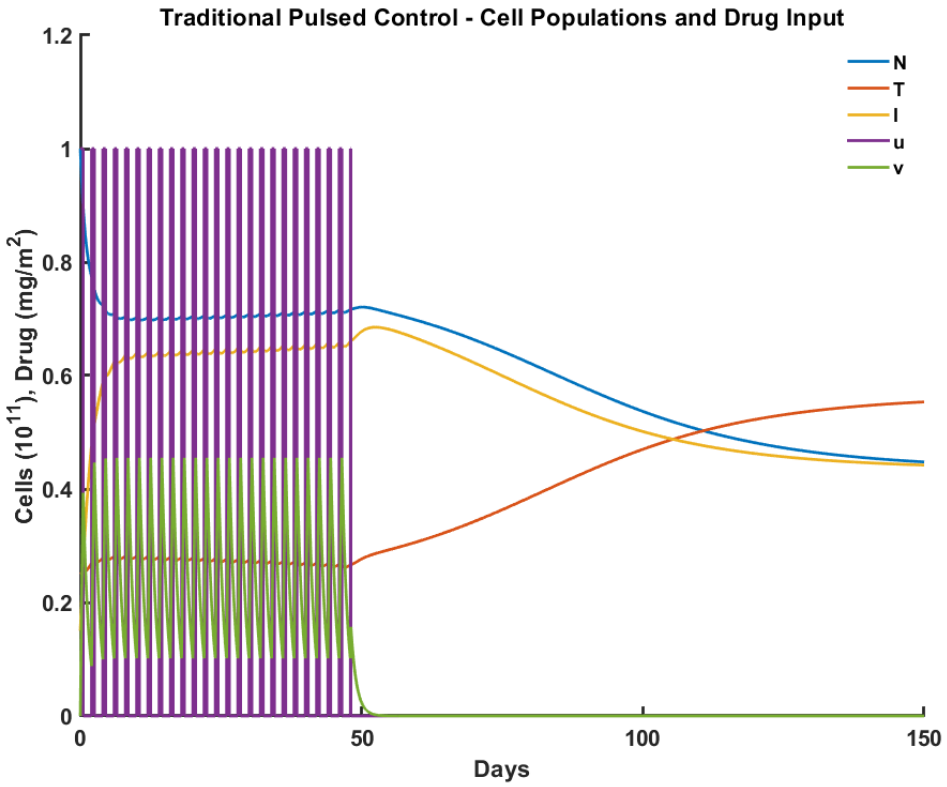

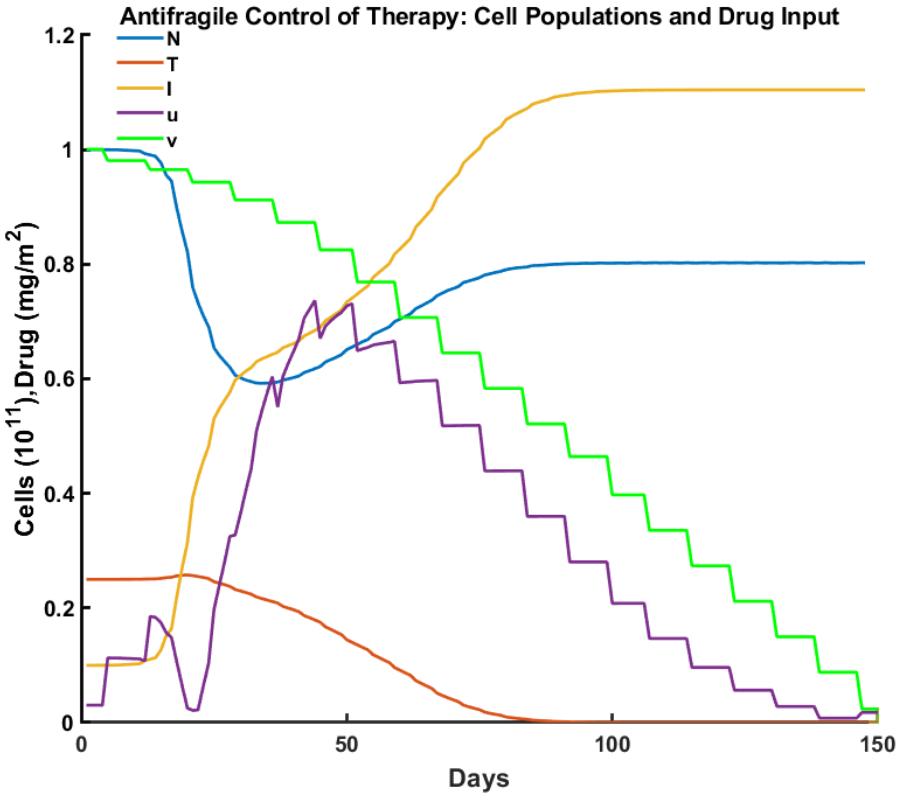

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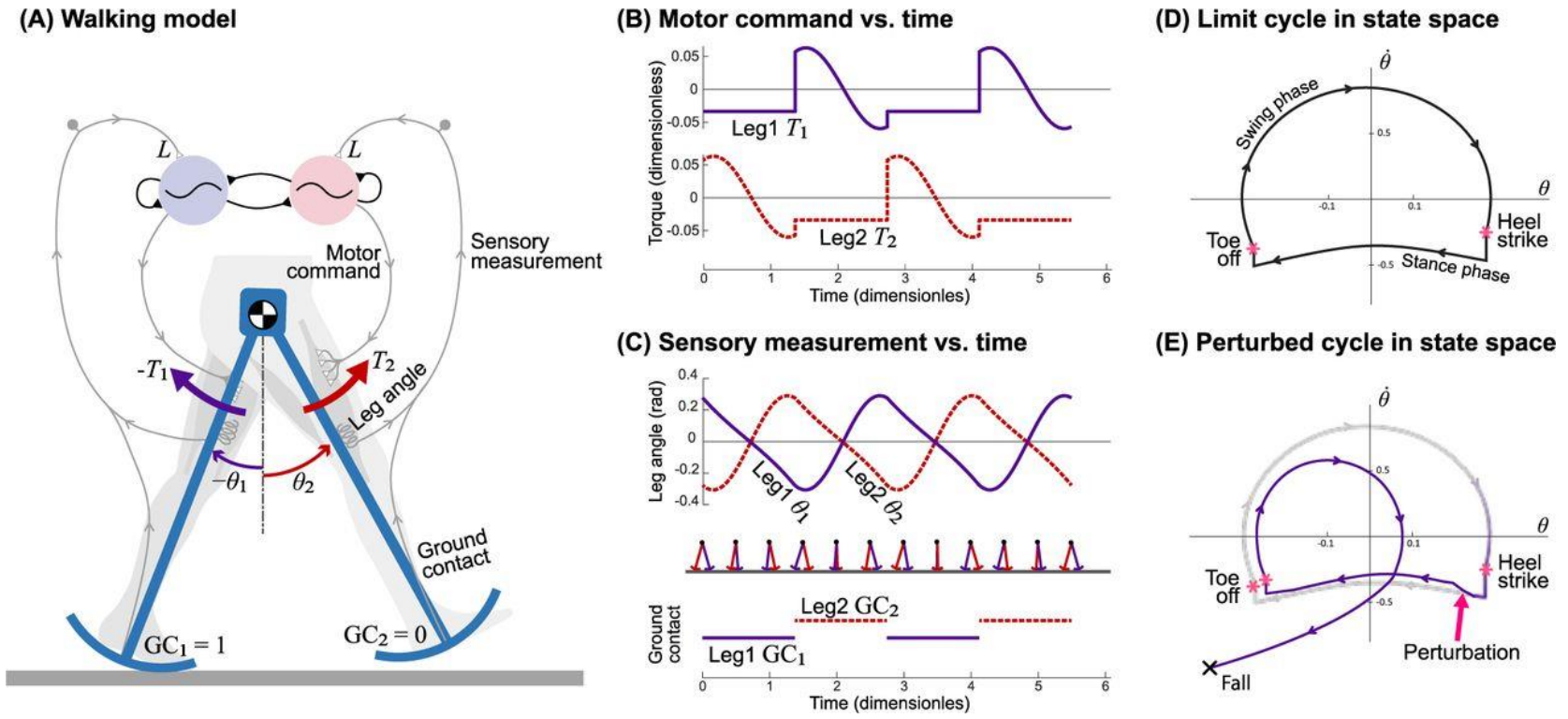
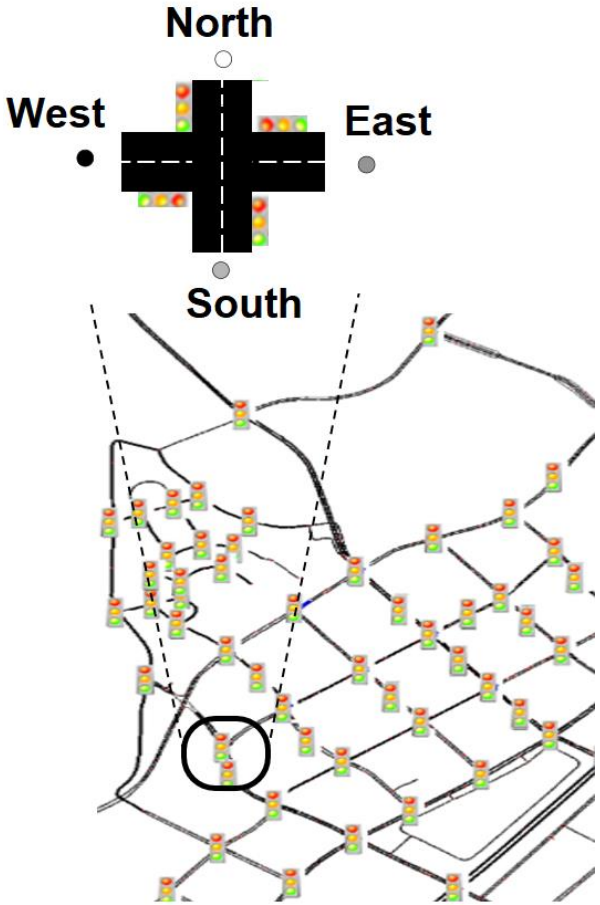
Antifragile feedback control: learning from biology



Source: https://www.biorxiv.org/content/10.1101/2019.12.30.890152v1.full

Antifragile feedback control: learning from biology



Single cross dynamics

Axenie, Cristian, and Margherita Grossi. "Antifragile control systems: The case of an oscillator-based network model of urban road traffic dynamics." *arXiv preprint arXiv:2210.10460* (2022).

Antifragile feedback control: learning from biology

Oscillator-based modelling and nonlinear control

Internal properties | Network coupling | External coupling | Control law

$$\frac{d\theta_i(t)}{dt} = \omega_i(t) + k_i(t)\sum_{j=1}^{N} A_{ij} sin(\theta_j(t) - \theta_i(t)) + F_i sin(\theta^*(t) - \theta_i(t)) + u_i(t)$$

with

$$u_i(t) = \epsilon_1 \int_0^t \hat{s}_i(\tau) d\tau$$

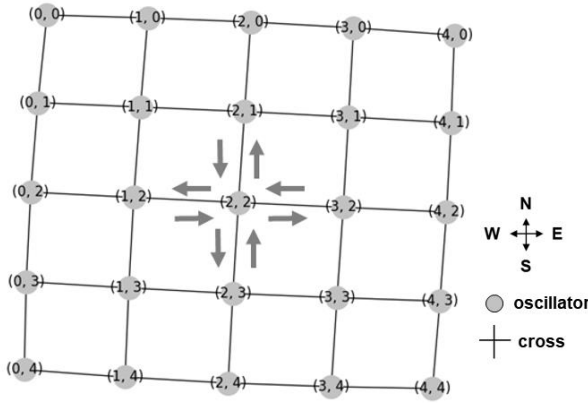
$$\frac{d\hat{s}_i(t)}{dt} = \epsilon_2 (\sum_{i,j} (\hat{s}_j(t) - \hat{s}_i(t)) + s_i(t))$$

$$\frac{ds_i(t)}{dt} = \epsilon_3 \sum_j (s_j(t) - \frac{d\hat{s}_i(t)}{dt}) - sign(\hat{s}_i(t)) \frac{d^2\theta_i(t)}{dt^2}$$

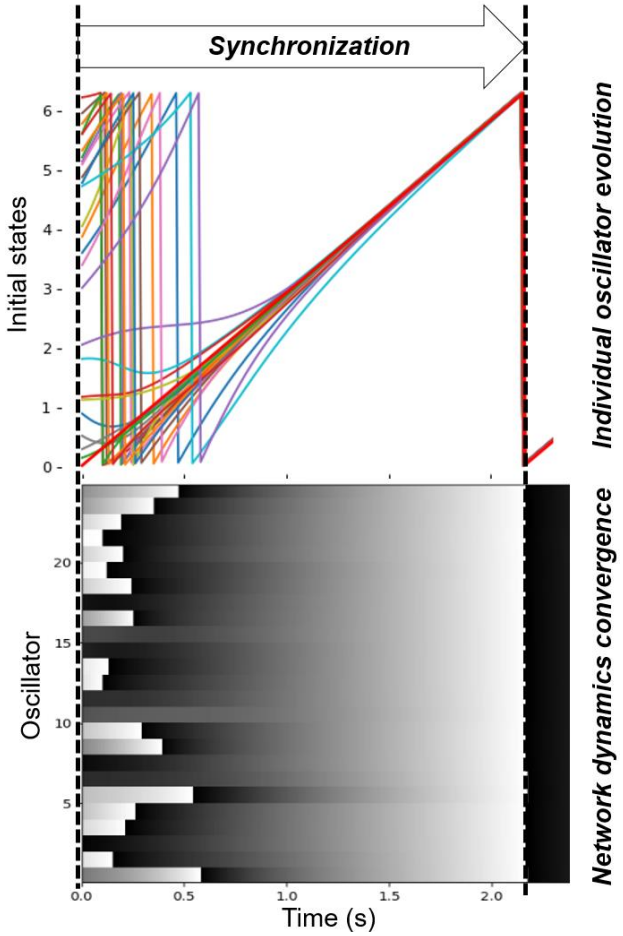
$$0 < \epsilon_1 < \epsilon_2 < \epsilon_3 < 1$$

where:
$s_i(t)$ - the surplus energy of traffic light i oscillator
$\hat{s}_i(t)$ - the estimated surplus energy of traffic light i oscillator

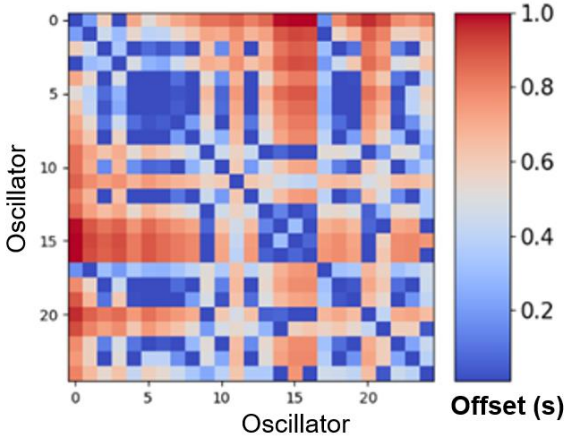
a. Example road network topology



b. Dynamics of the oscillator network



c. Time to synchronization (offset)



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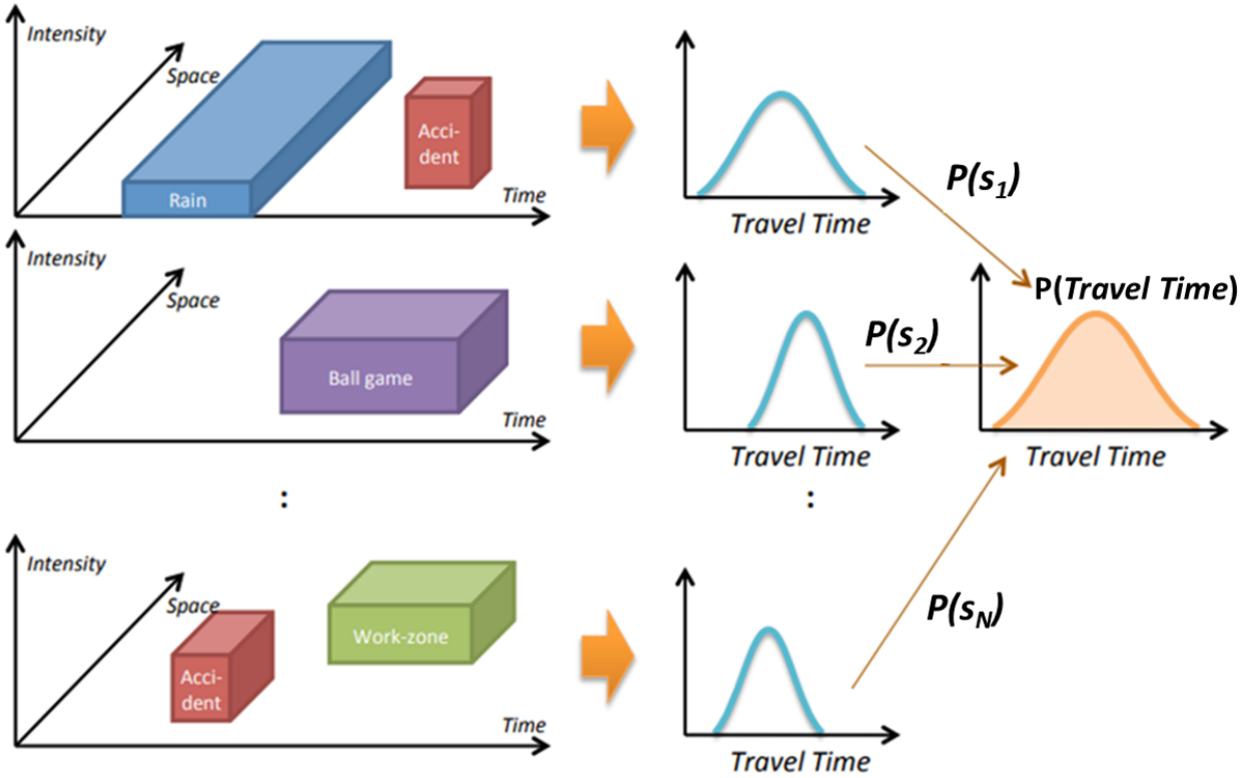
Antifragile feedback control: transfer to technology



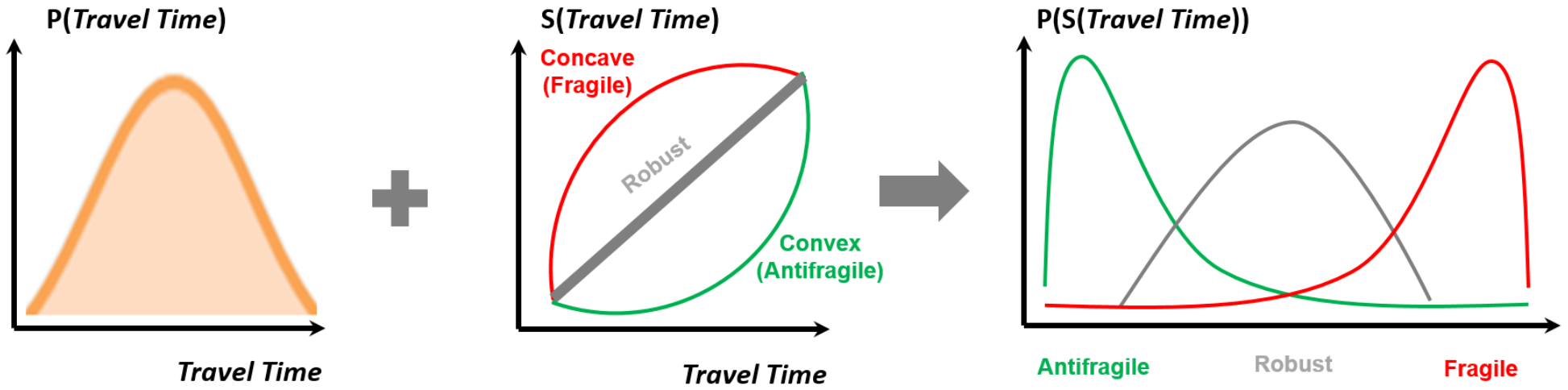
Uncertainty sources (space-time-intensity traffic disruptions)

Signal recomputation alters travel time distribution

Travel time responses to signal recomputation

Axenie, Cristian, and Margherita Grossi. "Antifragile control systems: The case of an oscillator-based network model of urban road traffic dynamics." *arXiv preprint arXiv:2210.10460* (2022).

Antifragile feedback control: transfer to technology



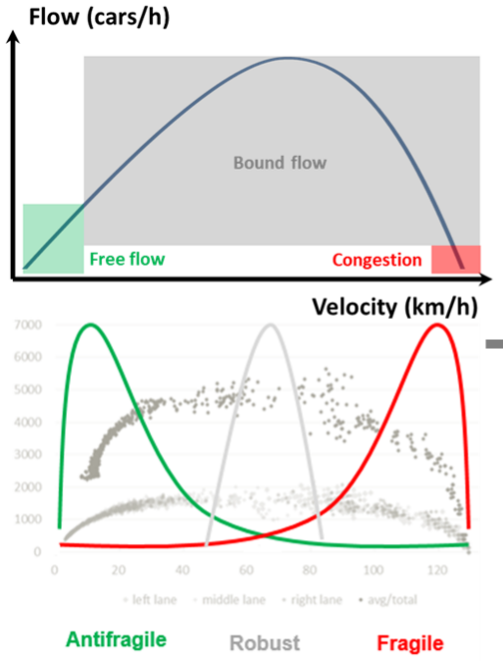
Distribution of travel time given recomputation with disruptions

Travel time response to signal recomputation

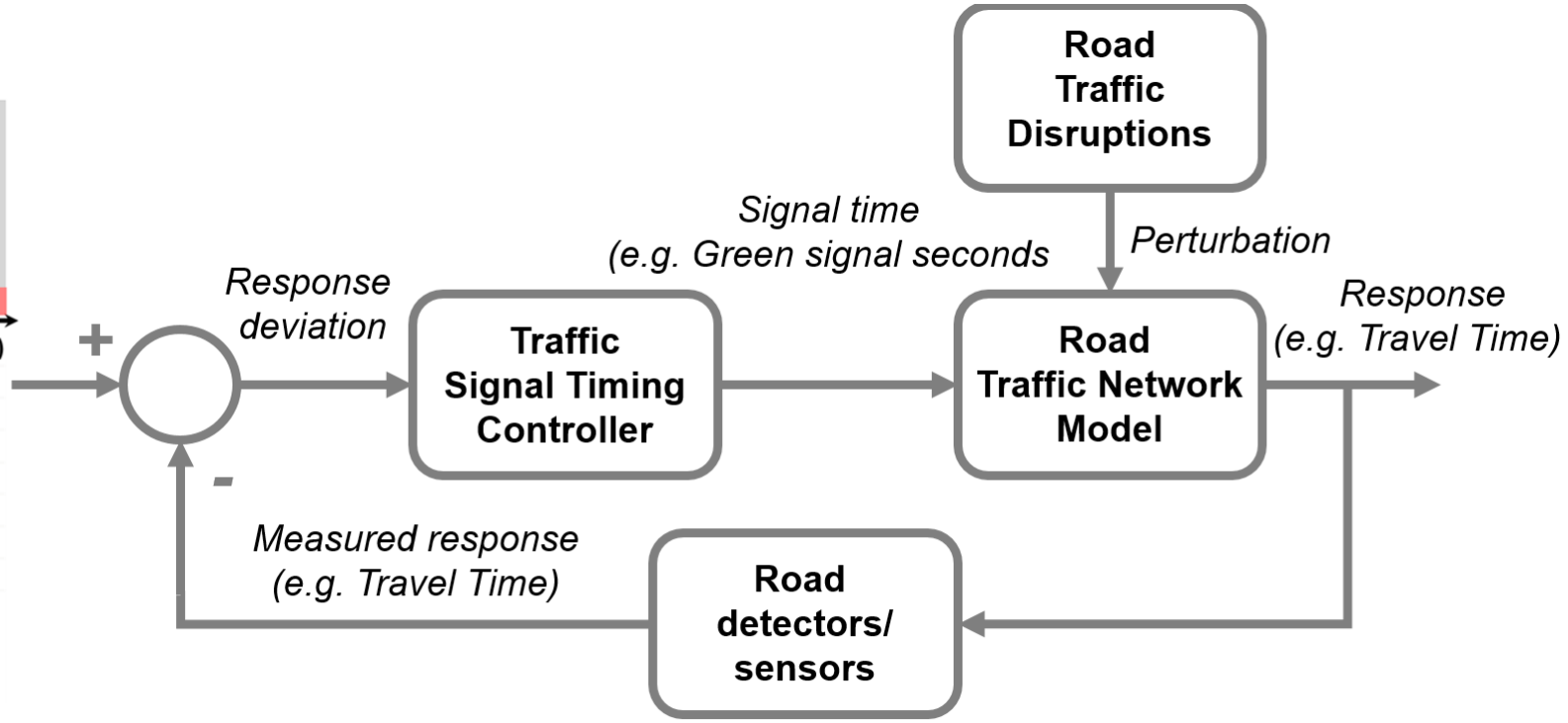
Distribution of responses to signal recomputation

Axenie, Cristian, and Margherita Grossi. "Antifragile control systems: The case of an oscillator-based network model of urban road traffic dynamics." *arXiv preprint arXiv:2210.10460* (2022).

Antifragile feedback control: transfer to technology



Stabilization into the antifragile region of MFD



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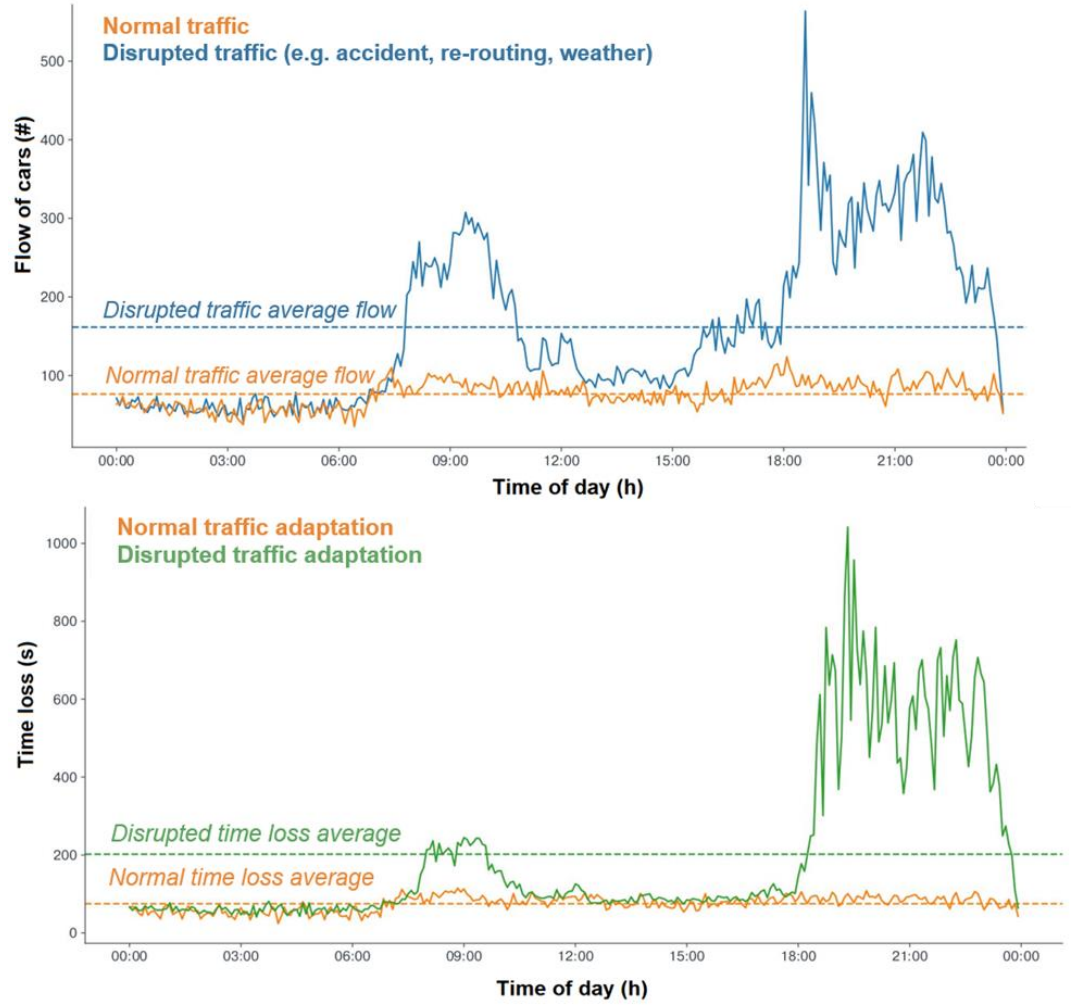
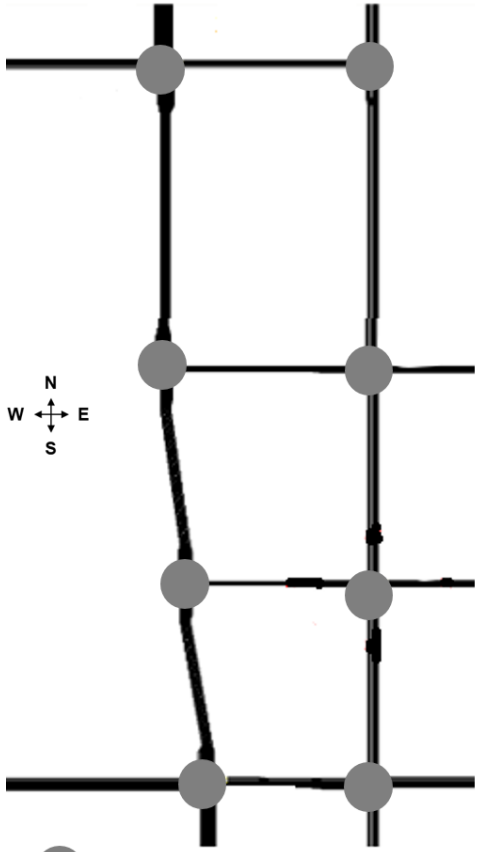
Antifragile feedback control: transfer to technology





Crosses
1 oscillator per direction
5 crosses with 4 directions
3 crosses with 3 directions

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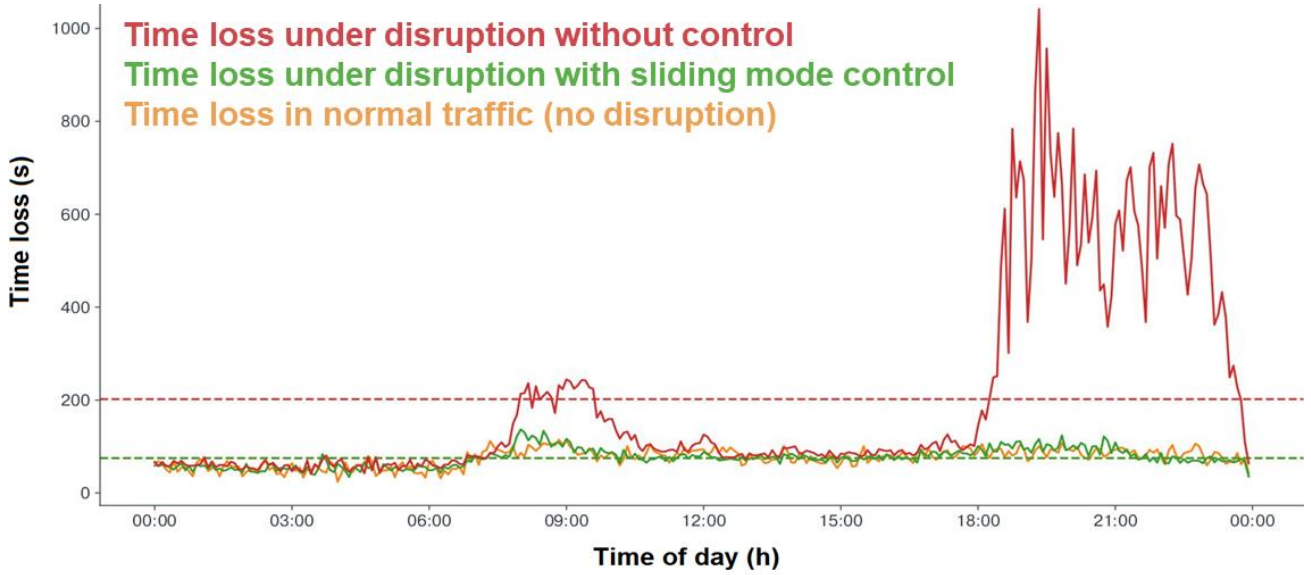
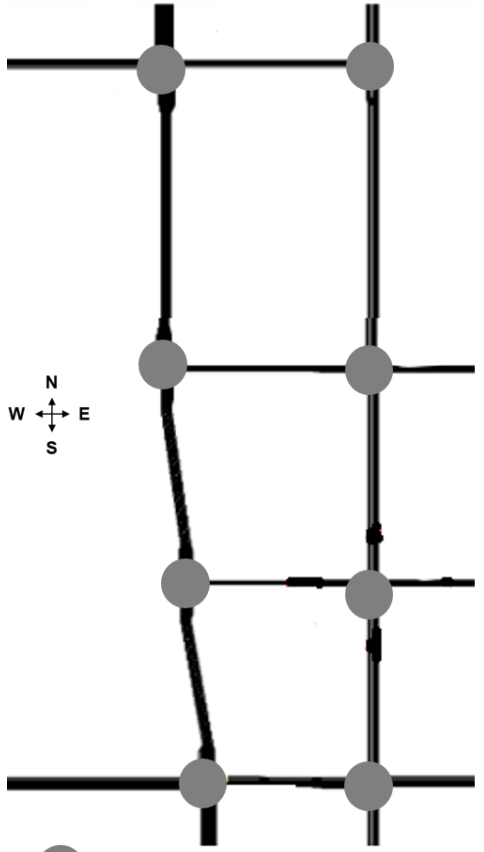
Antifragile feedback control: transfer to technology





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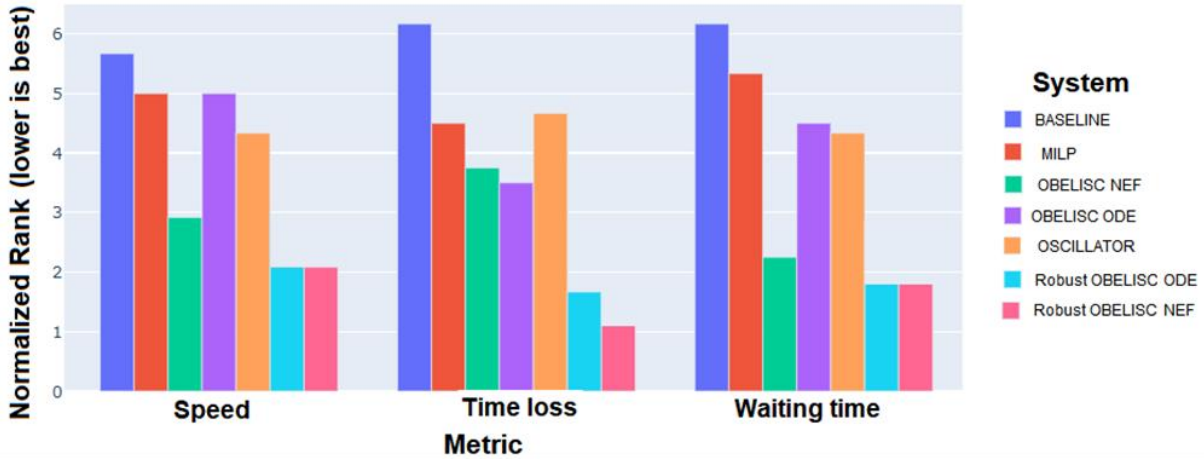
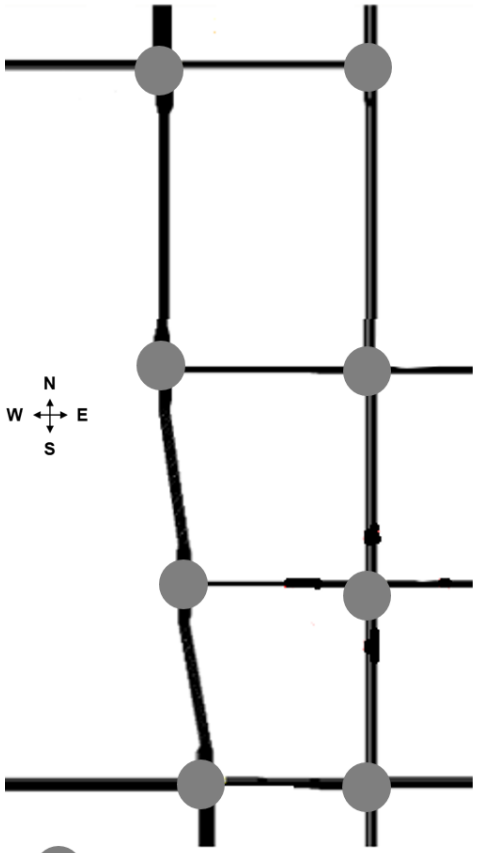


Model	Single cross	Region (8 crosses)
MILP	0.0510	0.3930
OSCILLATOR	0.0568	0.4544
Robust OBELISC ODE	0.0489	0.4534
Robust OBELISC NEF	**0.0071**	**0.0426**

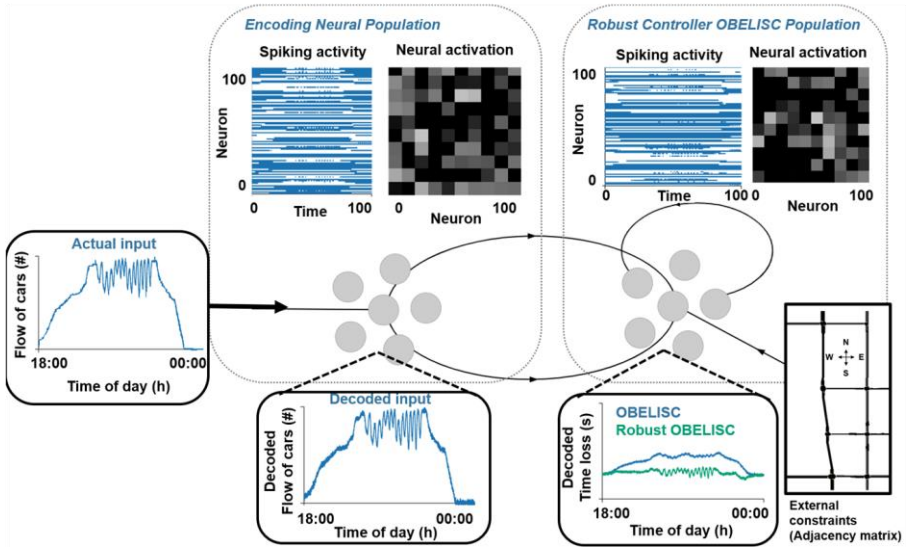


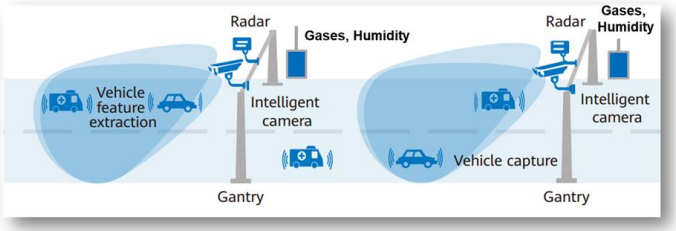
Crosses
1 oscillator per direction
5 crosses with 4 directions
3 crosses with 3 directions

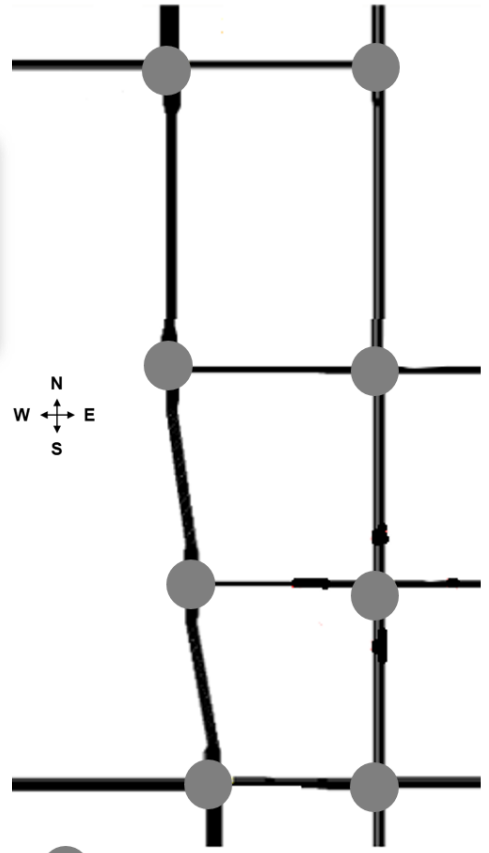
Axenie, Cristian, and Margherita Grossi. "Antifragile control systems: The case of an oscillator-based network model of urban road traffic dynamics." *arXiv preprint arXiv:2210.10460* (2022).

Antifragile feedback control: transfer to technology

Efficient neural learning







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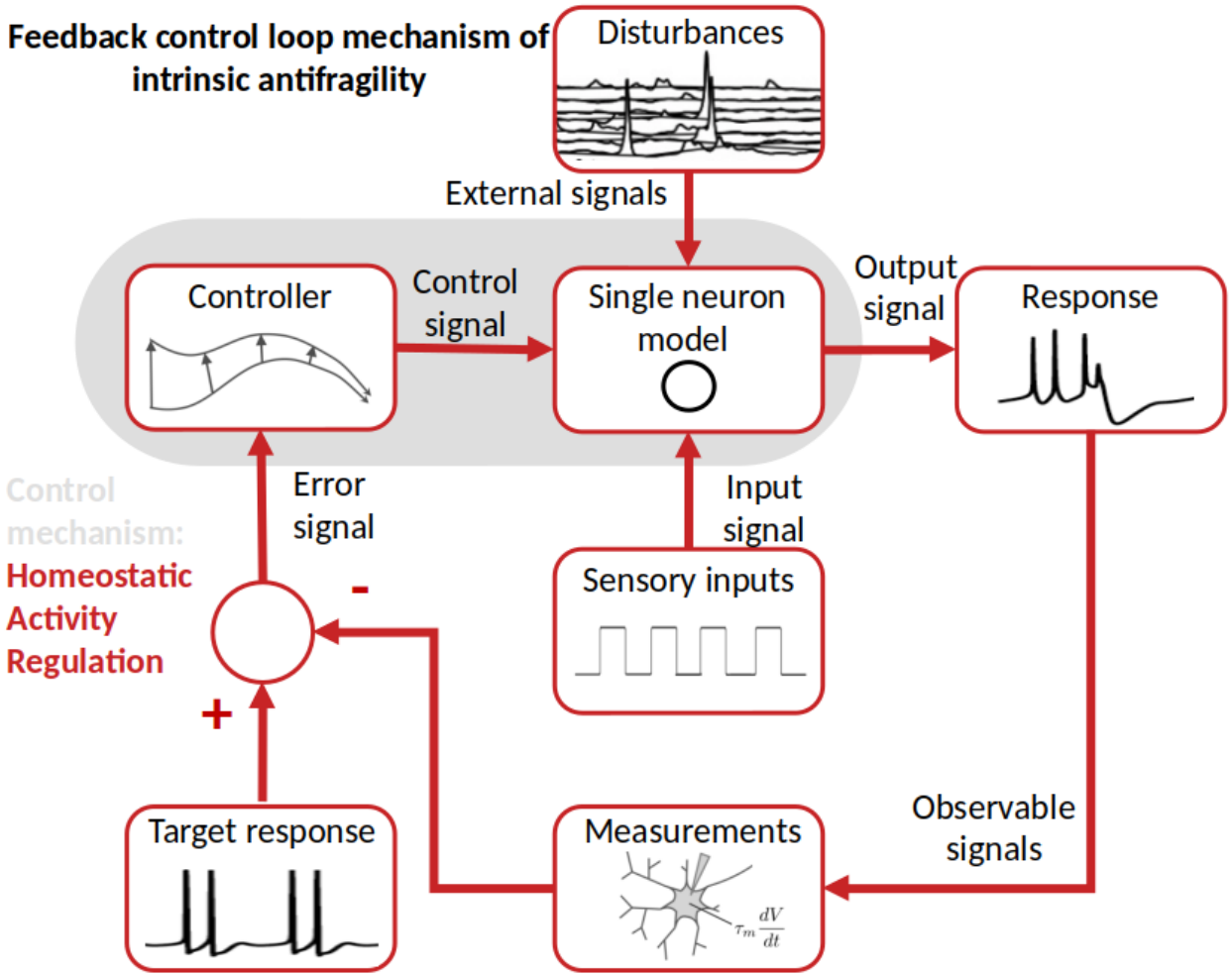
Antifragile feedback control: learning from biology



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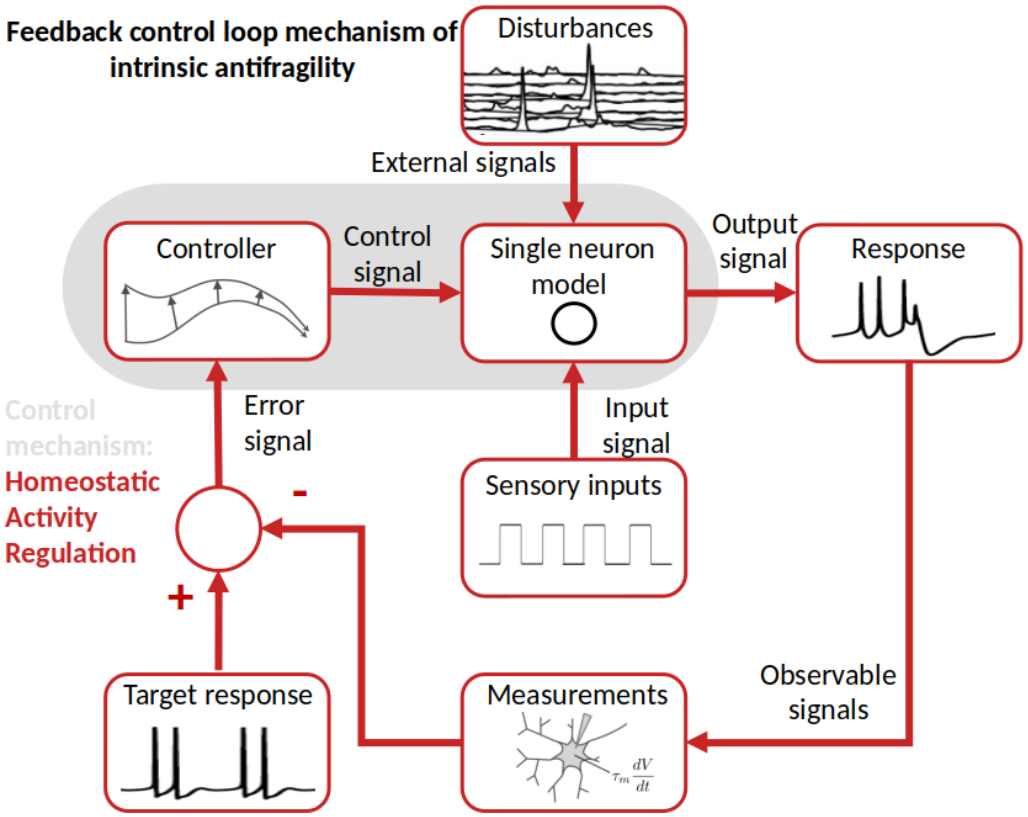
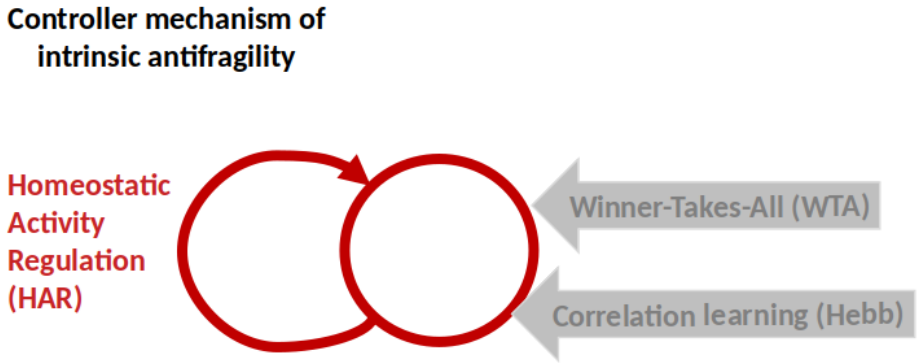
Antifragile feedback control: learning from biology





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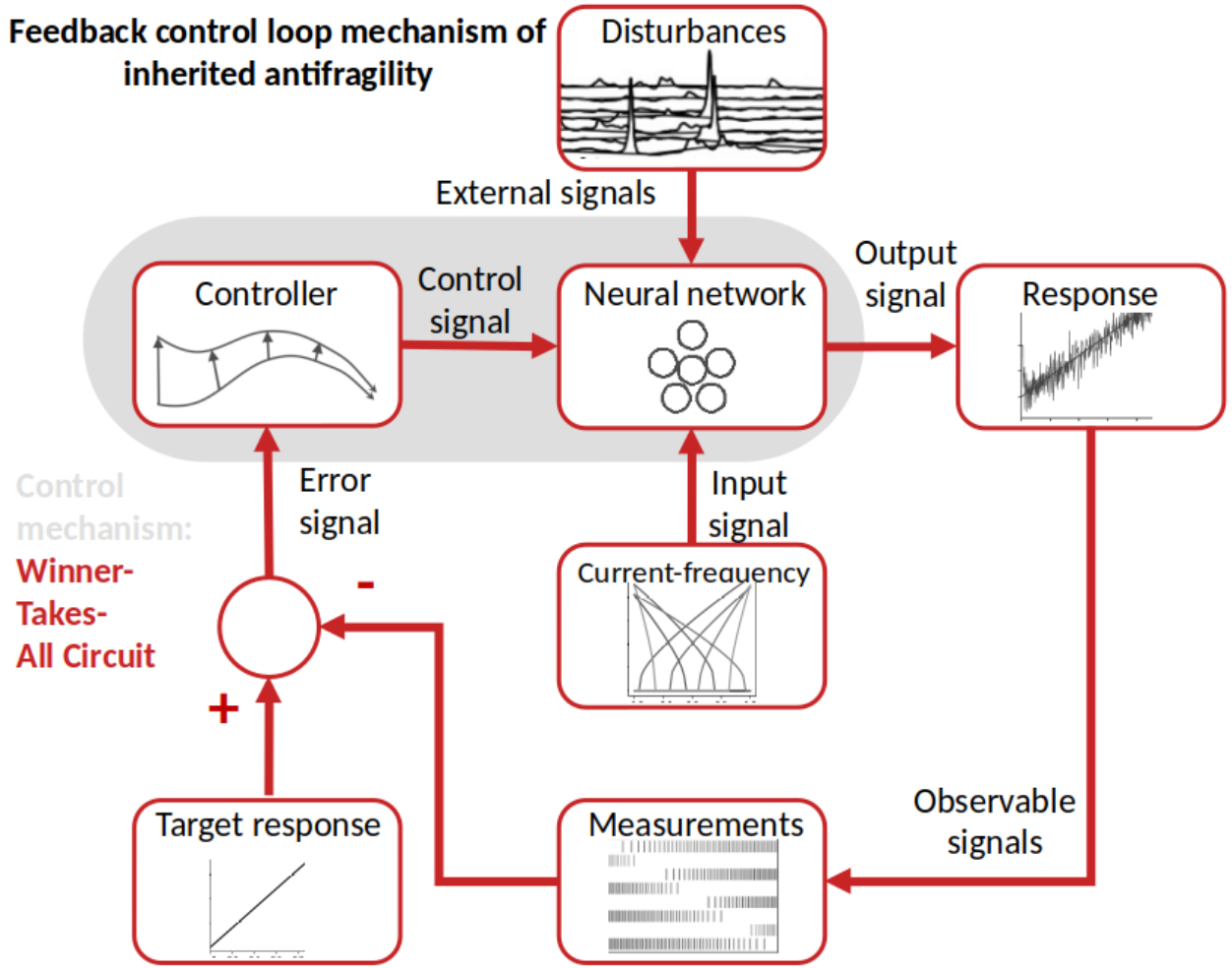

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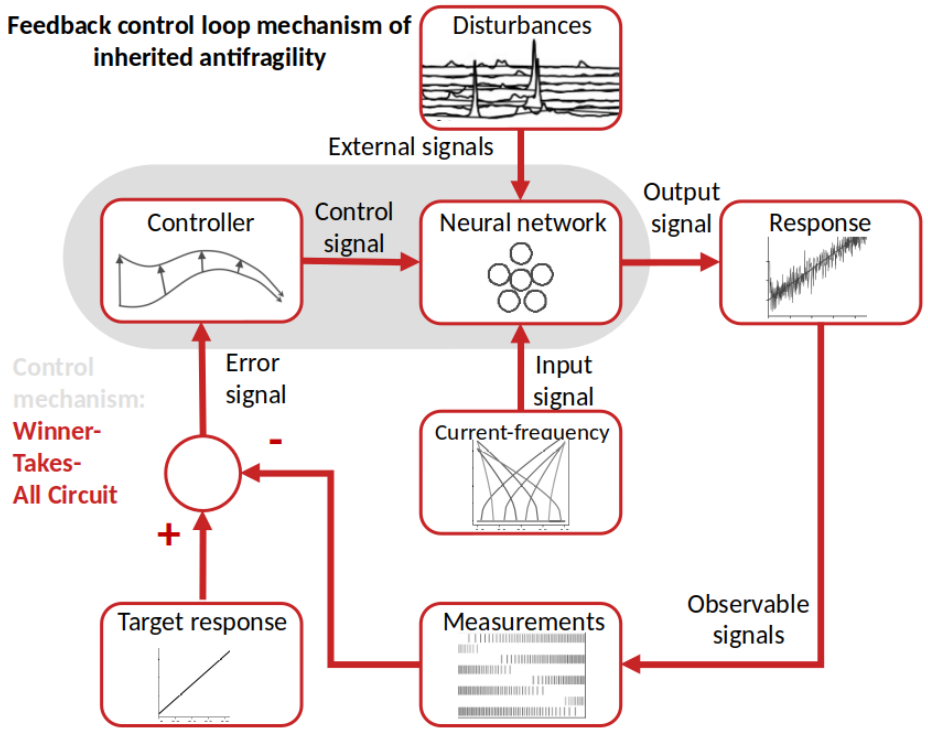

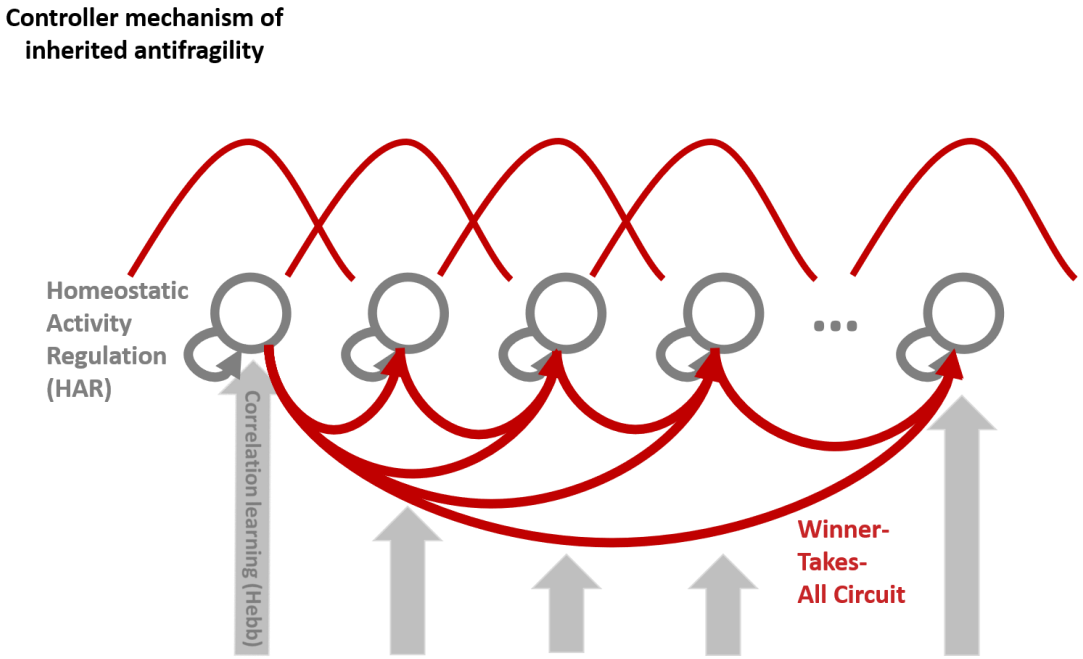

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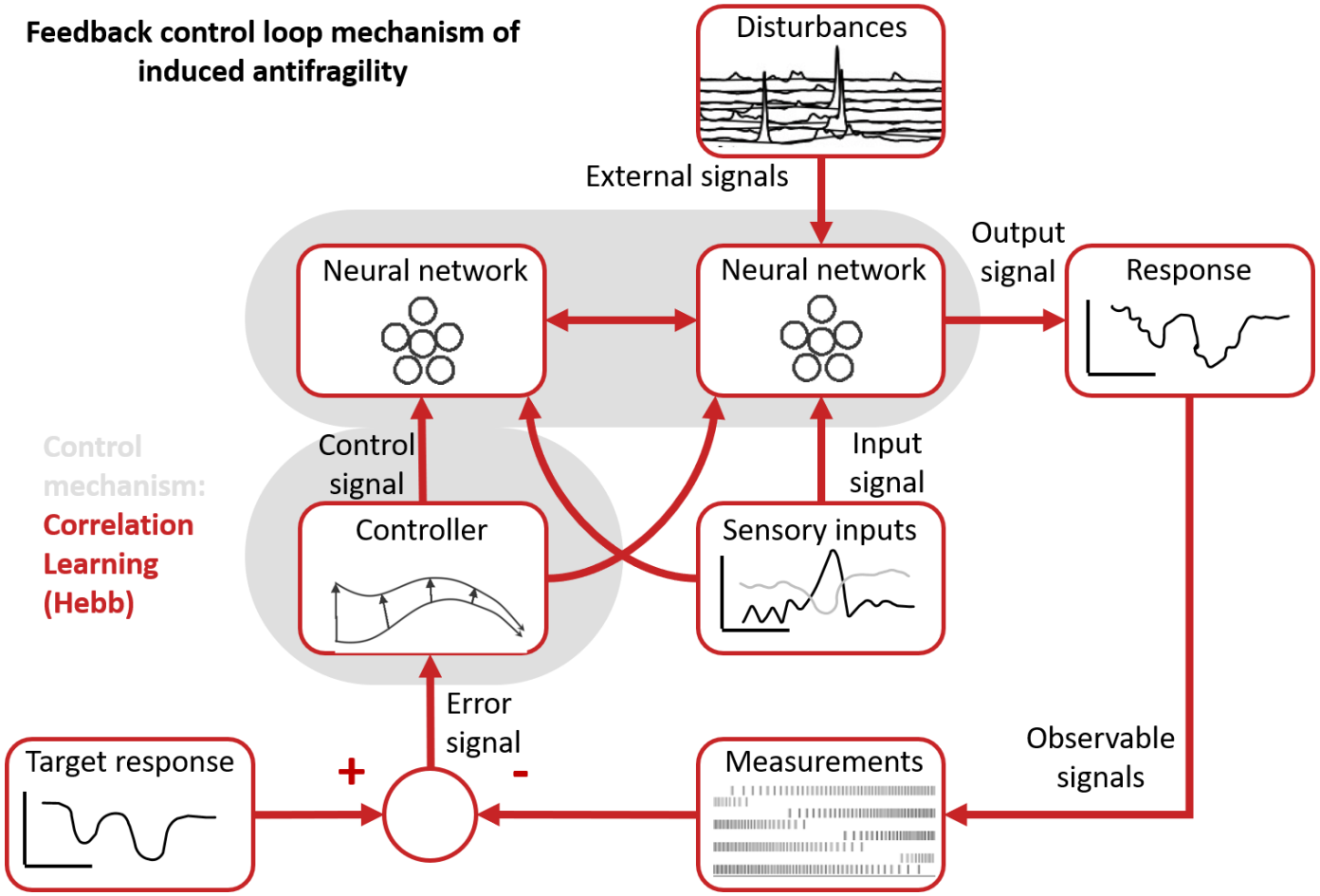

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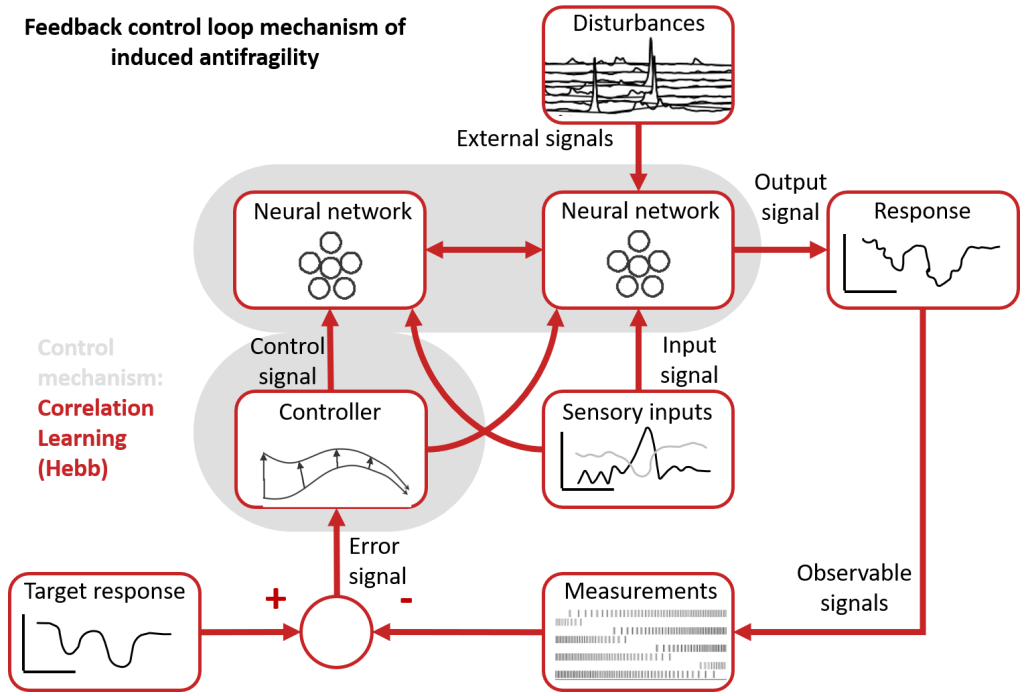

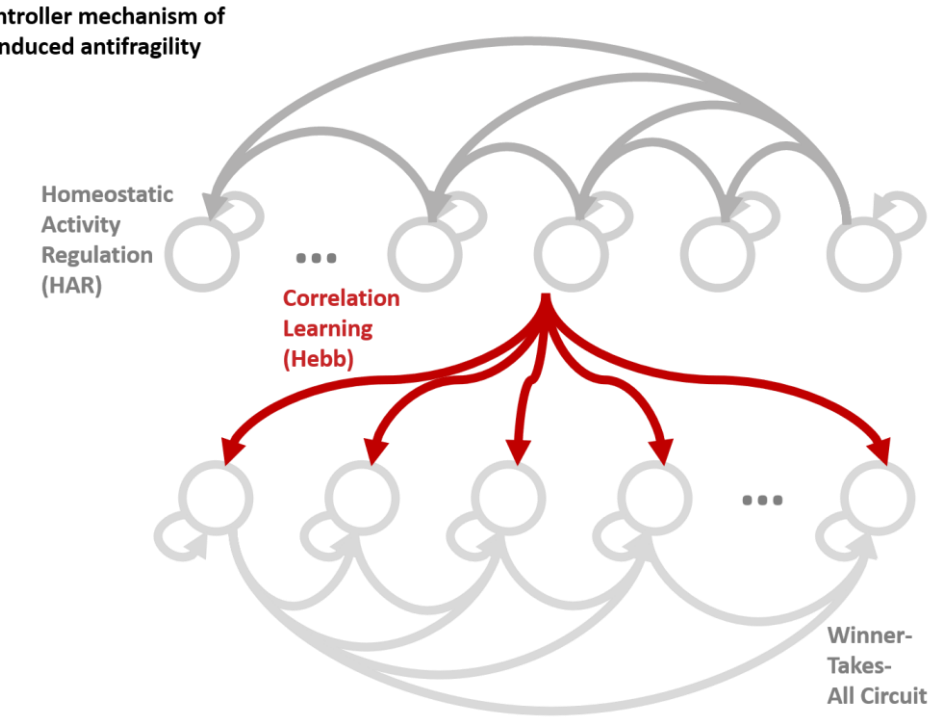

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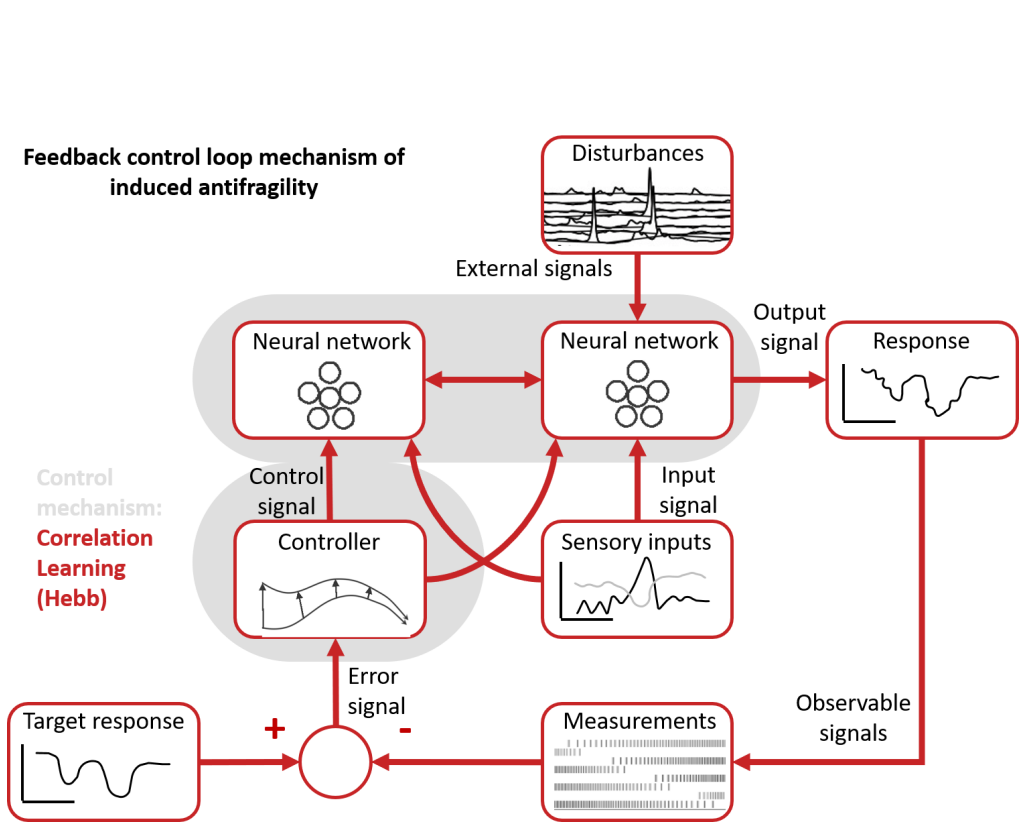
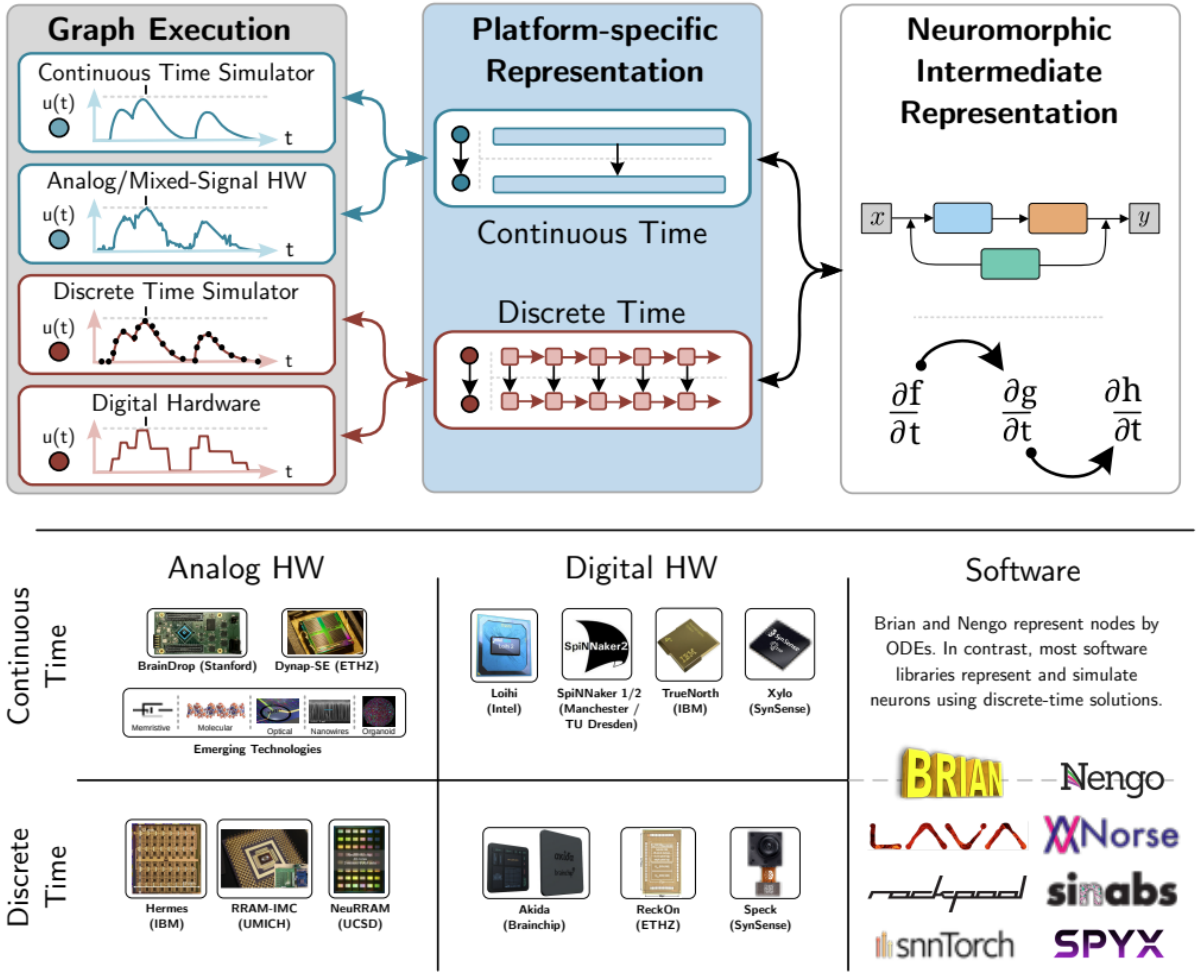
Antifragile feedback control: transfer to technology





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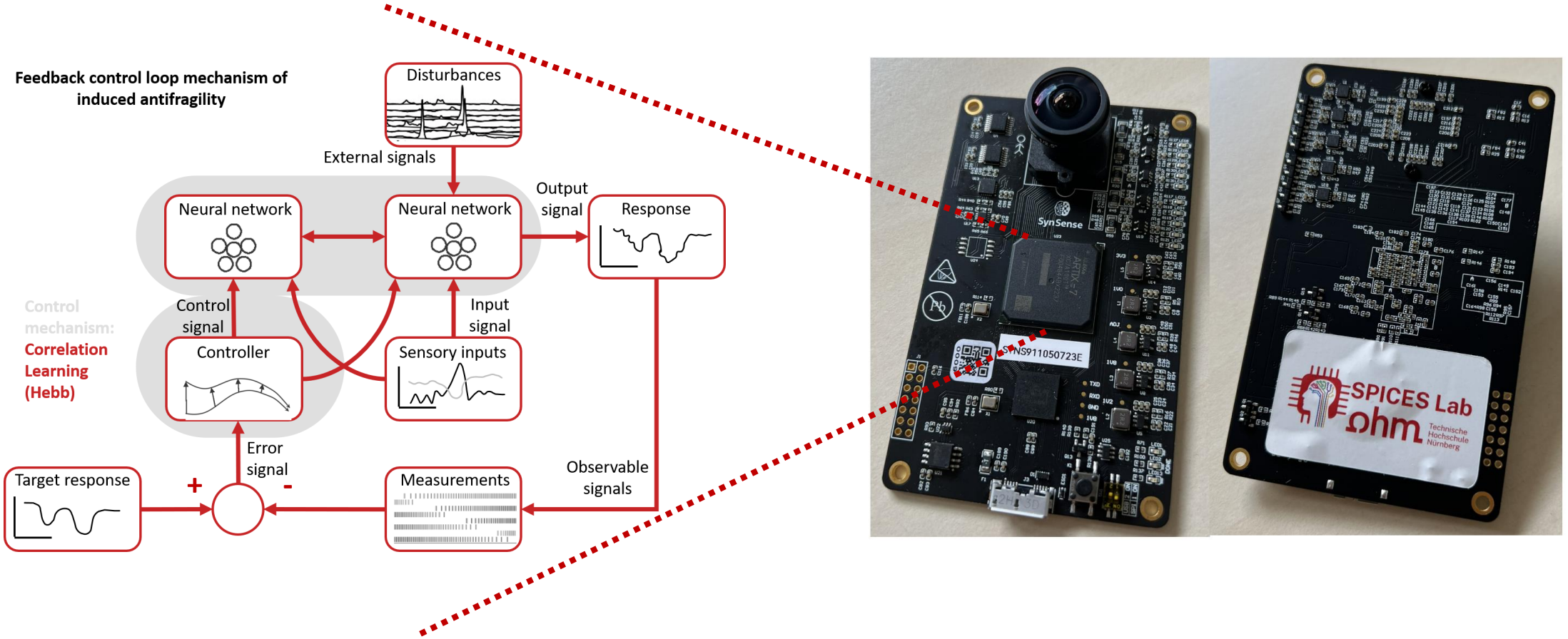
Source: Pedersen, Jens E., et al. "Neuromorphic intermediate representation: a unified instruction set for interoperable brain-inspired computing." *arXiv preprint arXiv:2311.14641* (2023).

Antifragile feedback control: transfer to technology



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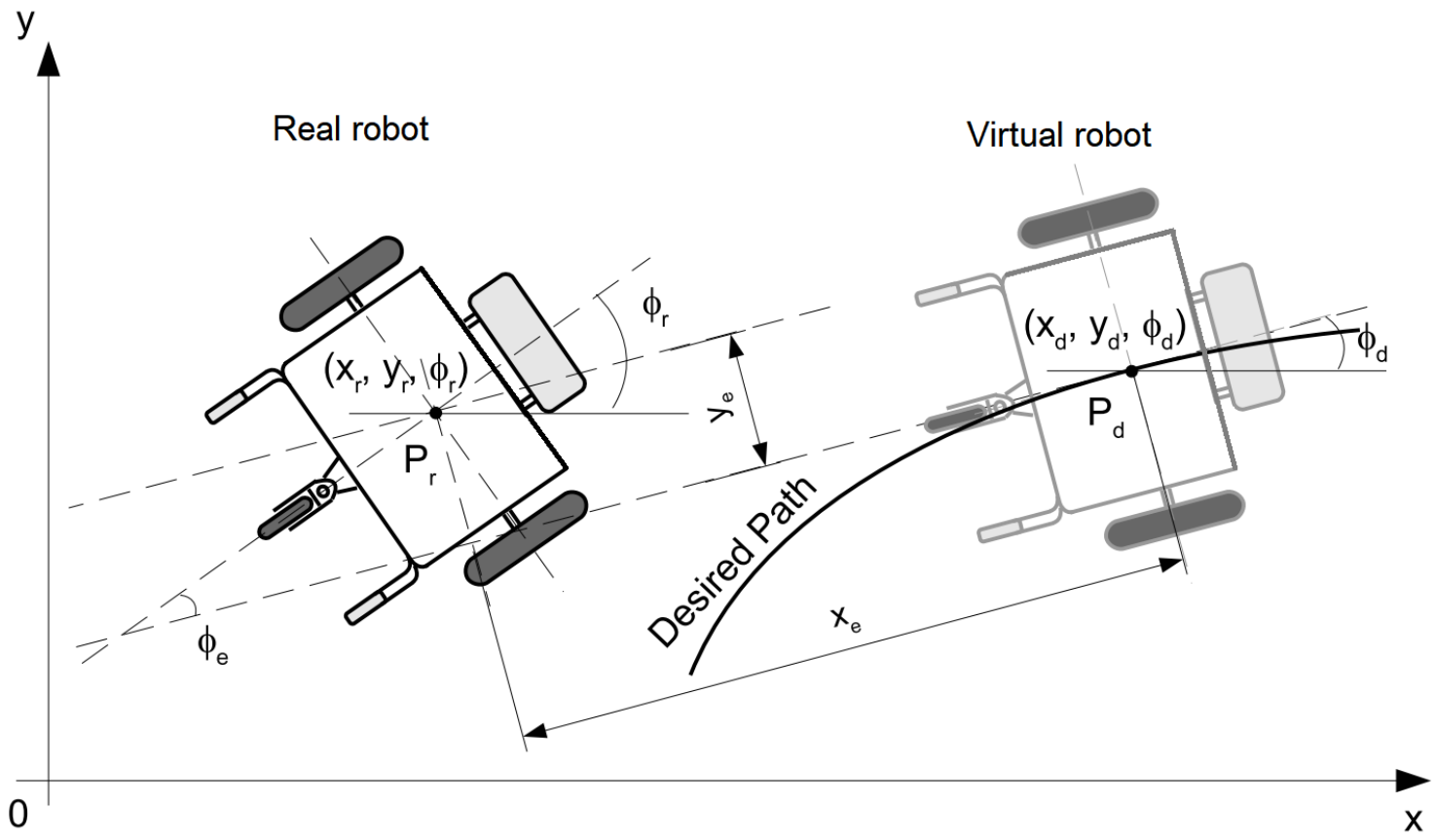
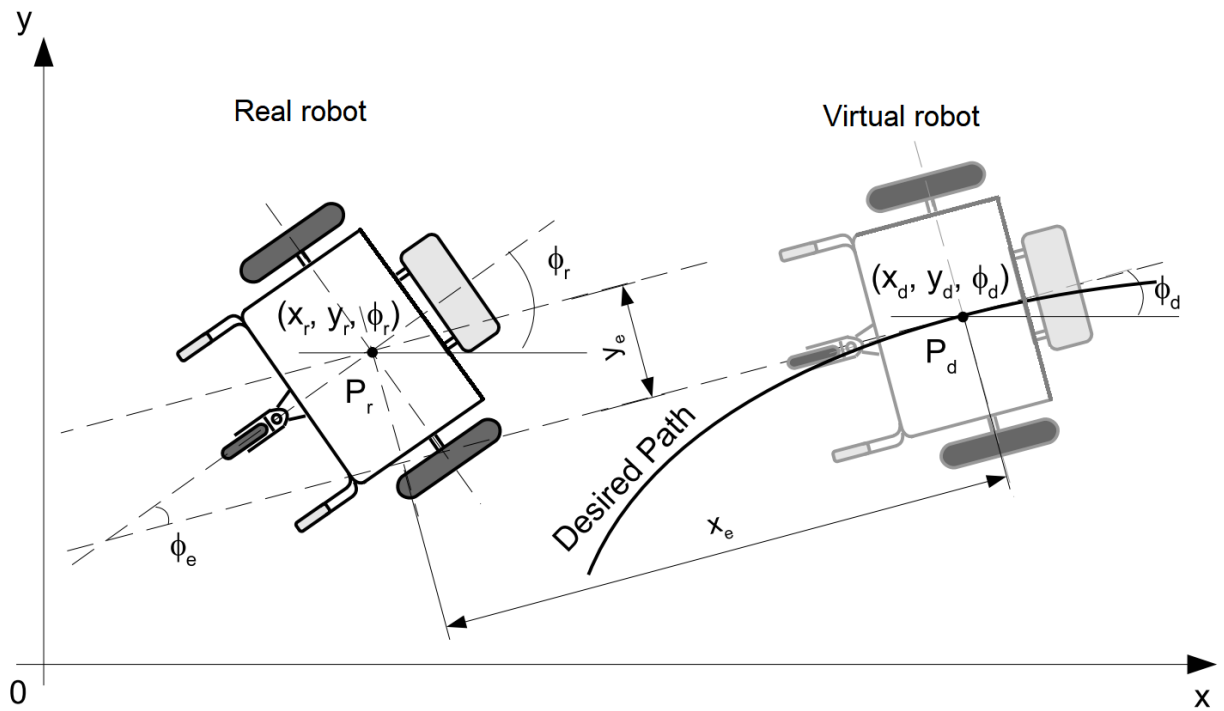
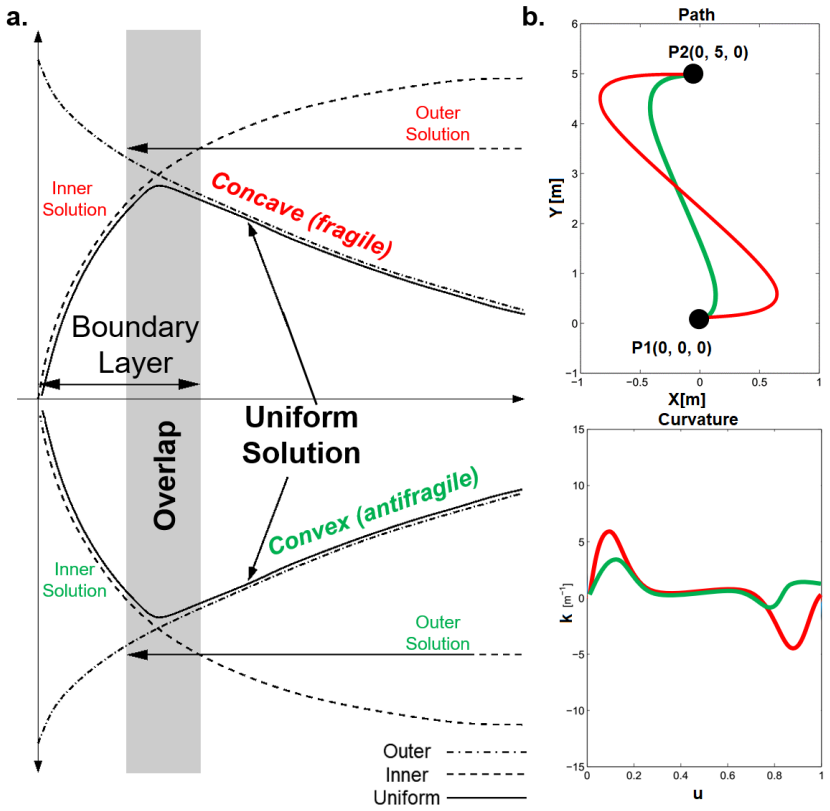


Axenie, Cristian, and Matteo Saveriano. "Antifragile Control Systems: The case of mobile robot trajectory tracking under uncertainty and volatility." IEEE Access (2023).
Source: https://www.oxygentimes.com/wheelchair/kosmocare-rider-automatic-reclining-electric-wheelchair

Antifragile feedback control: transfer to technology





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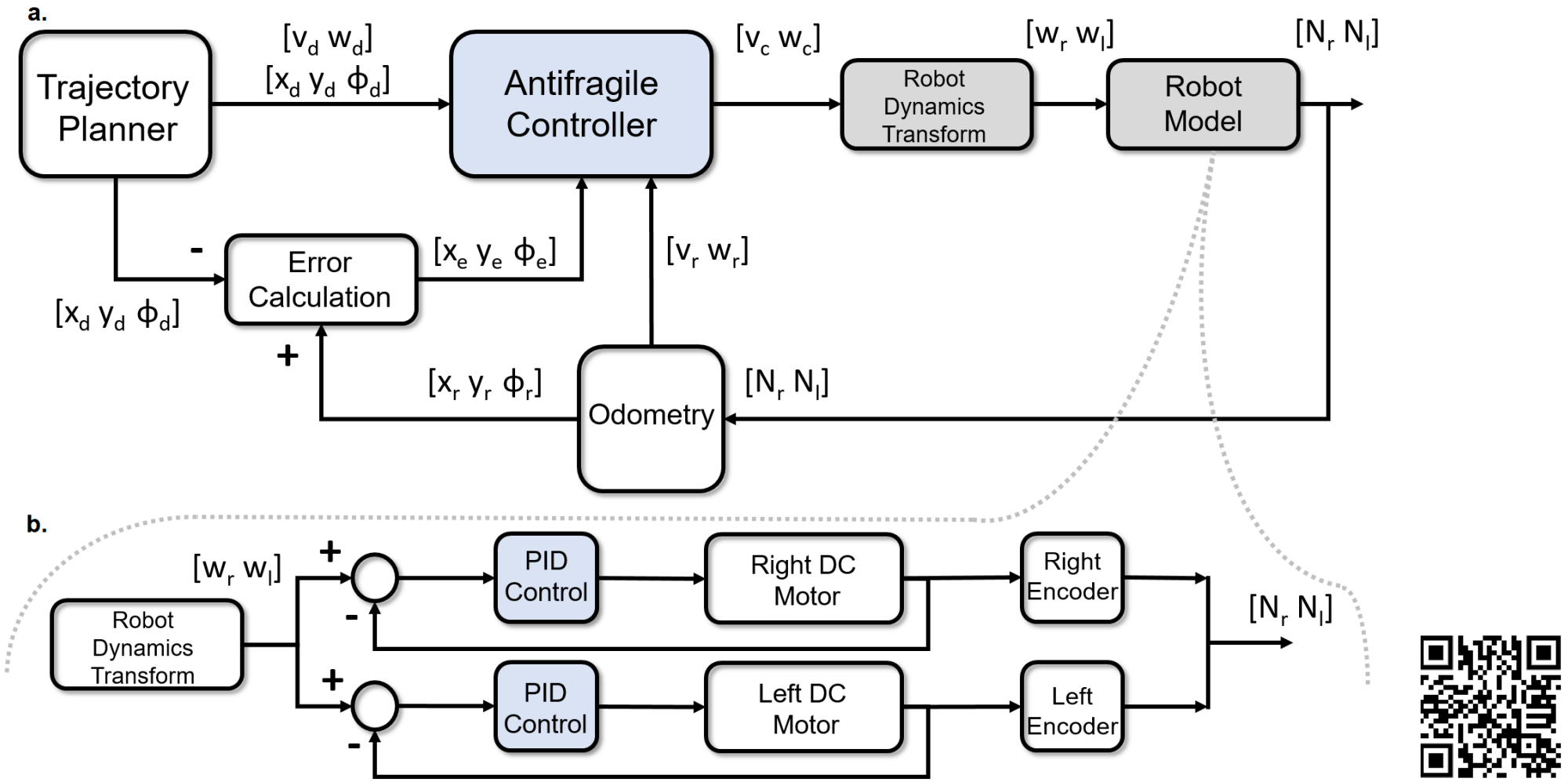

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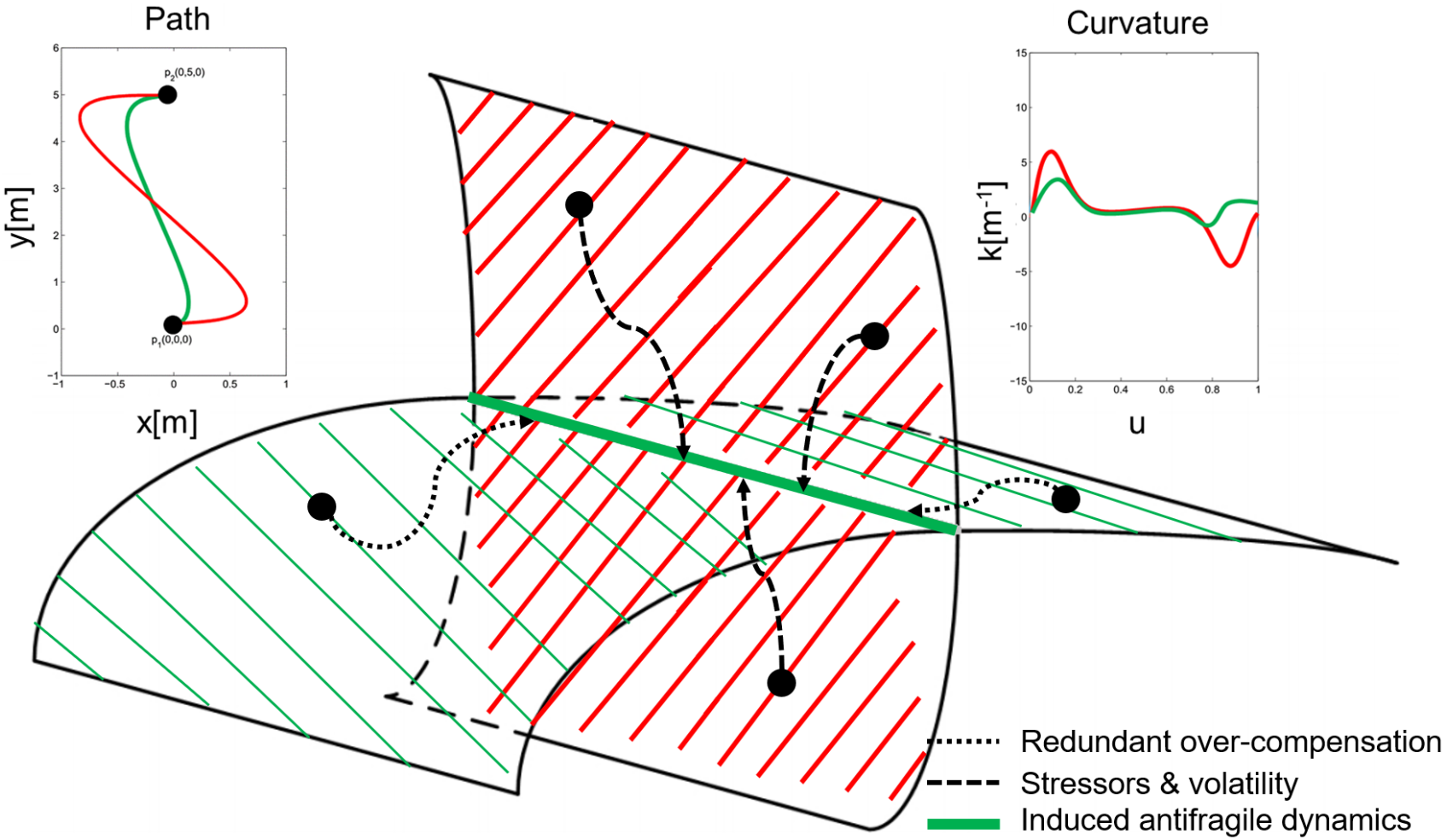

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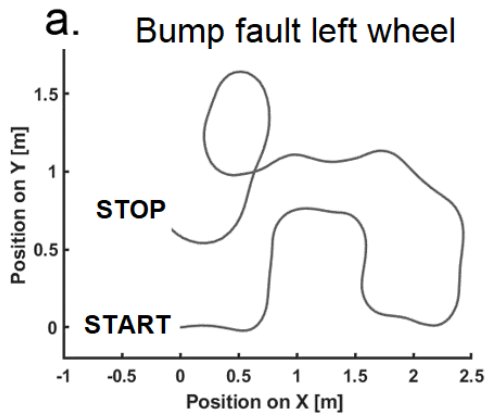

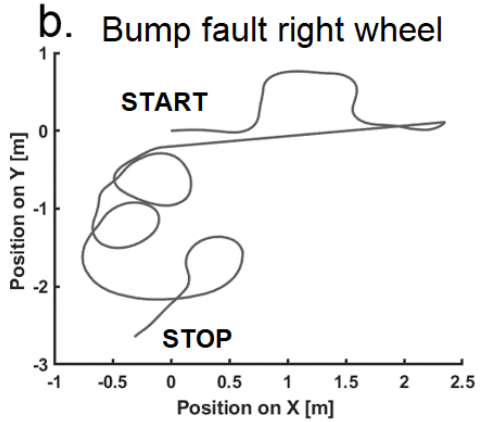

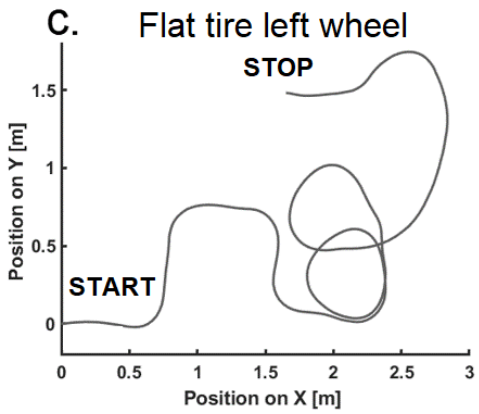

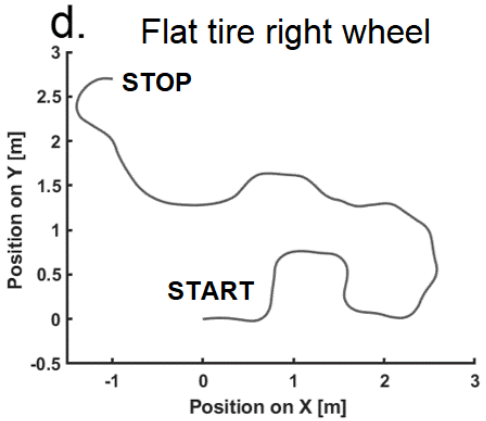

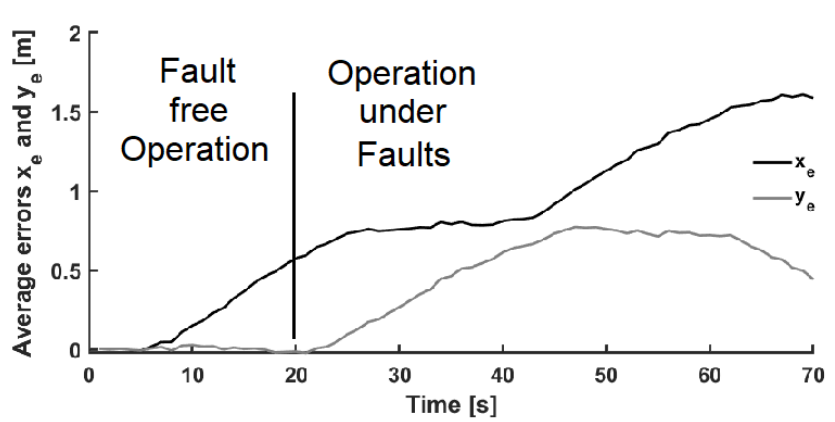

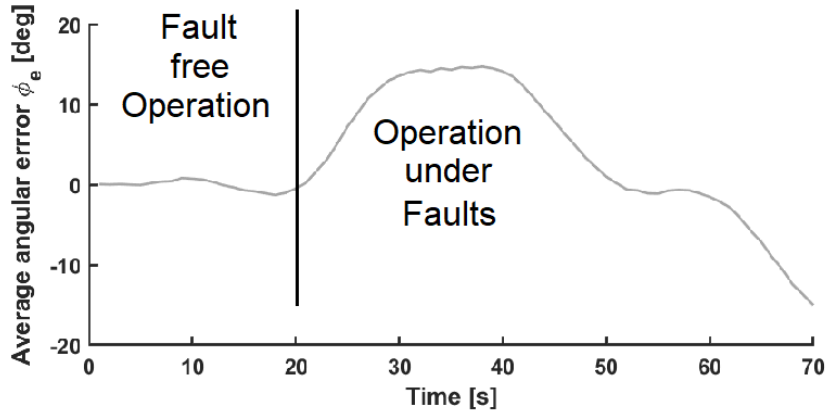

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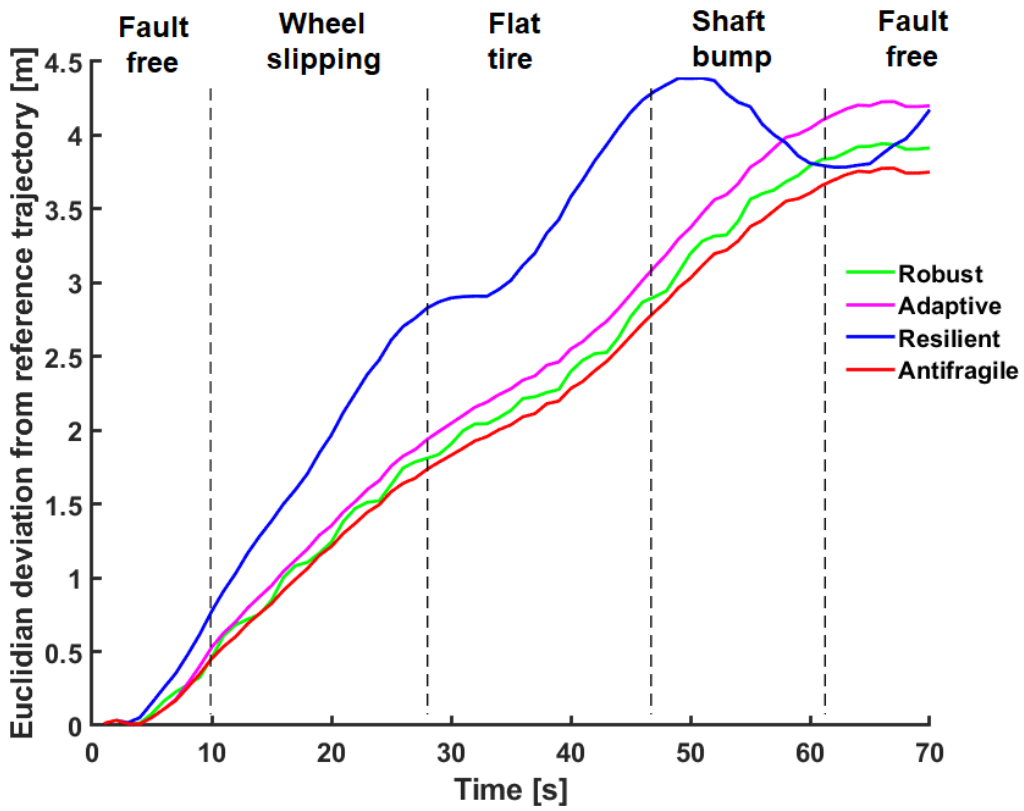

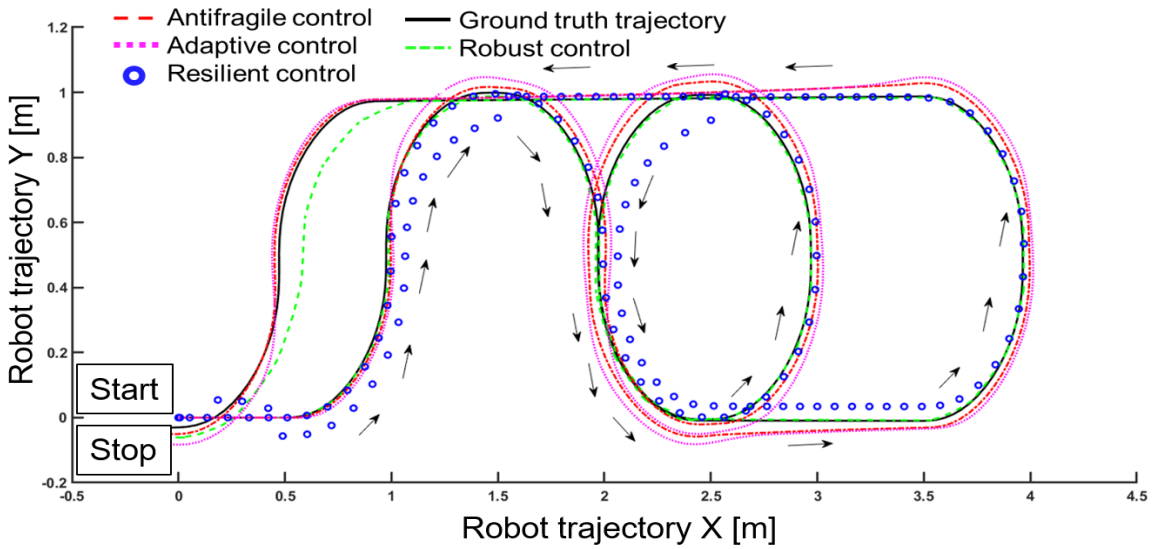

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ANTIFRAGILITY
gain from uncertainty

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