Diversity-enabled sweet spots in \textit{layered architectures} and speed-accuracy trade-offs in sensorimotor control

Yorie Nakahira, Quanying Liu, Terrence J. Sejnowski, and John C. Doyle

\textbf{PNAS 2021}

\begin{equation}
\delta \left( \sum_{i=1}^{T} |a^{i-1}| + \left( 2^{V} - |a| \right)^{-1} \right)
\end{equation}
External feedback is standard from sensors to actuators.

Internal feedback is more complex.

Dominated by internal delays.
Internal feedback in the cortical perception-action loop enables fast and accurate behavior

Jing Shuang (Lisa) Li\textsuperscript{a,1}, Anish A. Sarma\textsuperscript{a,b,1}, Terrence J. Sejnowski\textsuperscript{c,d}, and John C. Doyle\textsuperscript{a}

PNAS 2023
Layers

Felleman & Van Essen, 1991
Internal feedback in the cortical perception-action loop enables fast and accurate behavior

Jing Shuang (Lisa) Li\textsuperscript{a,1}, Anish A. Sarma\textsuperscript{a,b,1}, Terrence J. Sejnowski\textsuperscript{c,d}, and John C. Doyle\textsuperscript{a}
Delays in blue signals?

Needs SLS

Beyond Bayes and Kalman

Unneeded in most engineering with fast electronics
System Level Synthesis

- Sense
- Comms
- Compute
- Actuate
- Plant

Sparse Delayed Quantized Control

Compute

Comms

Plant

Sense

Actuate
New Control theory

Planning

Reflex

Slow

Plan

Fast

Tradeoff

Theory?

Flexible

Local, distributed

Centralized

Stable virtual

Unstable dynamics
Tradeoff?

Flexible

Centralized

Stable

Fast

Cheap fast electronics

Controller
Fast, local, distributed, unstable dynamics.

Cheap slow biology

Spare
Delayed
Quantized

Sense
Comms
Compute
Actuate

Tradeoff

Reflex

Local, distributed
Unstable dynamics

Fast

Nerve cells
Everything:
  • Sparse
  • Delayed
Everything:
- Sparse
- Delayed
- Layered
Central
Dense
Delayed

Comms
Sense
Actuate

Sparse
Delayed

comp
Comms modeled as if in sense/act
Everything:
• Sparse
• Delayed

Need SLS

Previously intractable.

Sense&Act
• Sparse
• Delayed

preSLS

Can do more than we realized.
How does SLS work?

Layers

Need SLS
Zoom into a patch

Patches are design choices

Layers
Zoom into a patch

Think global, act local

Design/implement in patches with coordinated objectives

Scalable and implementable

(Overlapping)

Patches are design choices
Review article

System level synthesis

James Anderson, John C. Doyle, Steven H. Low, Nikolai Matni

*Department of Computing and Mathematical Sciences, California Institute of Technology, Pasadena CA, 91125, United States

†Departments of Electrical Engineering and Computer Science UC Berkeley, Berkeley CA, 94720, United States