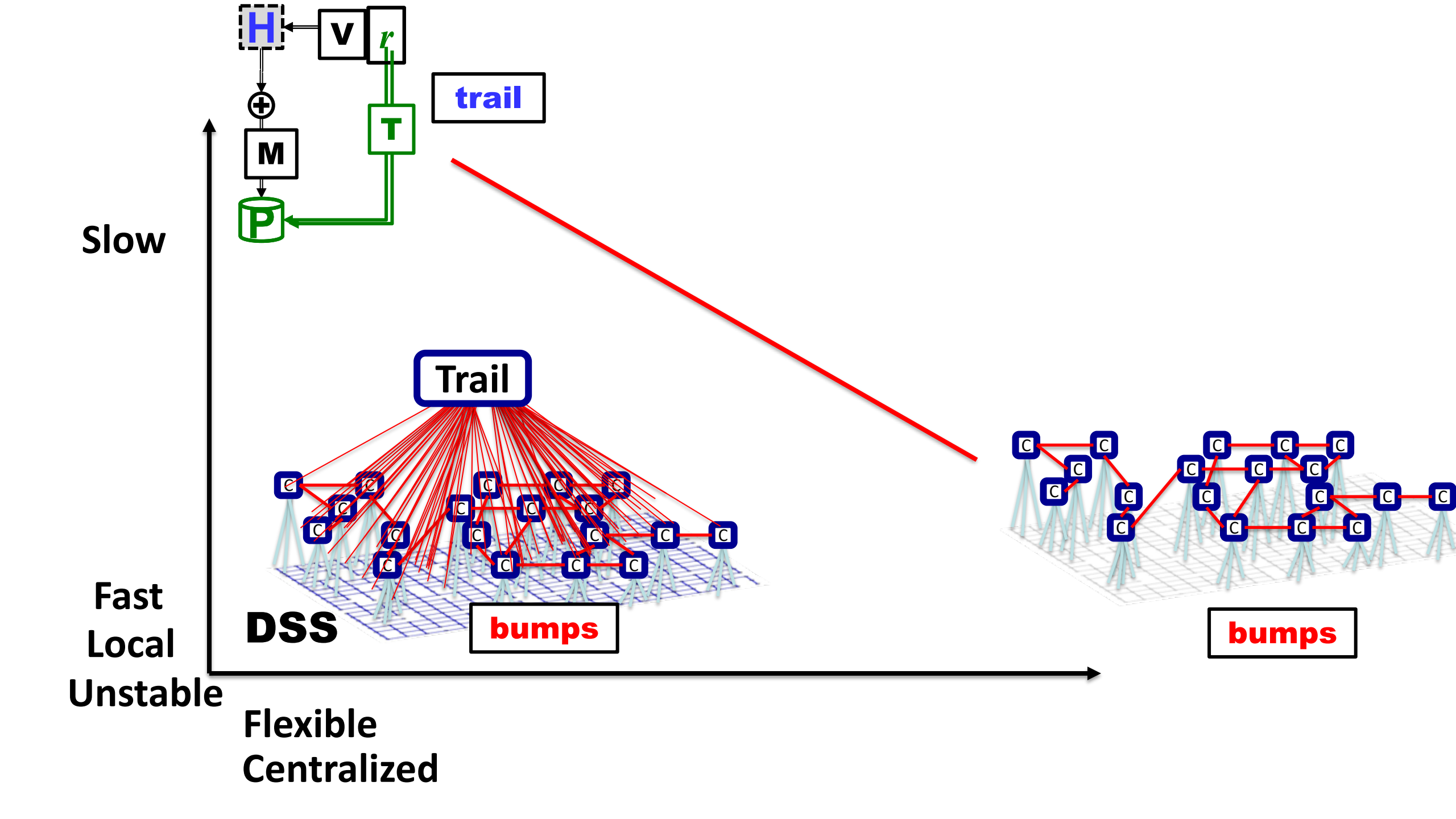
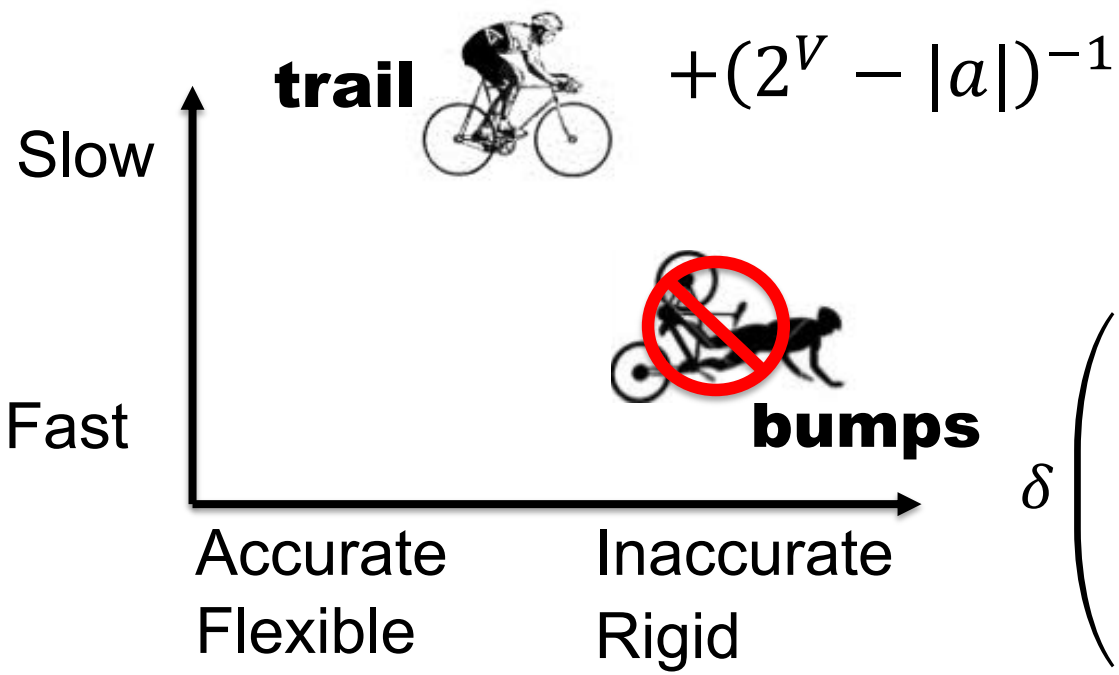

H
V
r
trail
T
M
P
Slow
Trail
bumps
DSS
bumps
Fast
Local
Unstable
Flexible
Centralized

Diversity-enabled sweet spots in layered architectures and speed-accuracy trade-offs in sensorimotor control

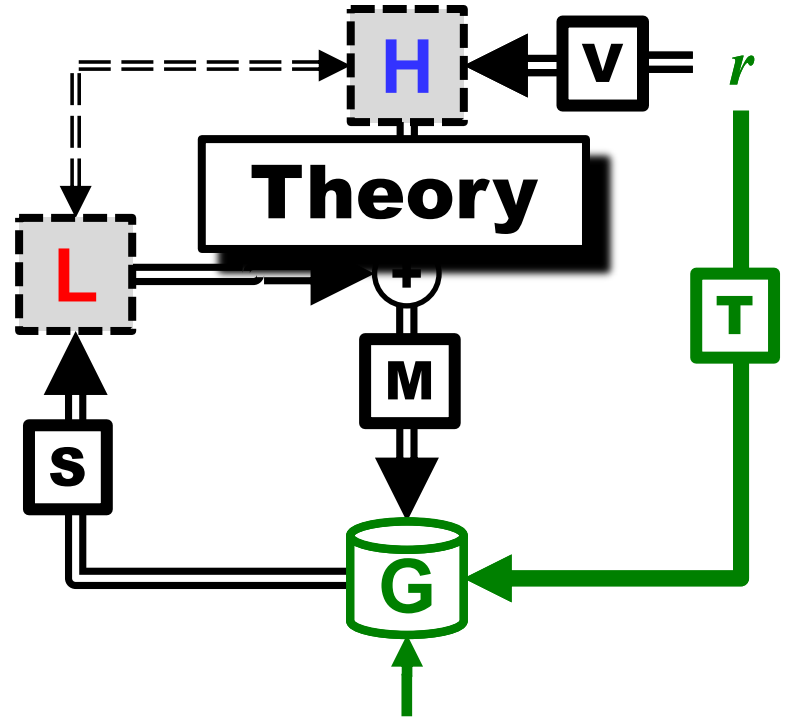
Yorie Nakahira, Quanying Liu, Terrence J. Sejnowski, and John C. Doyle

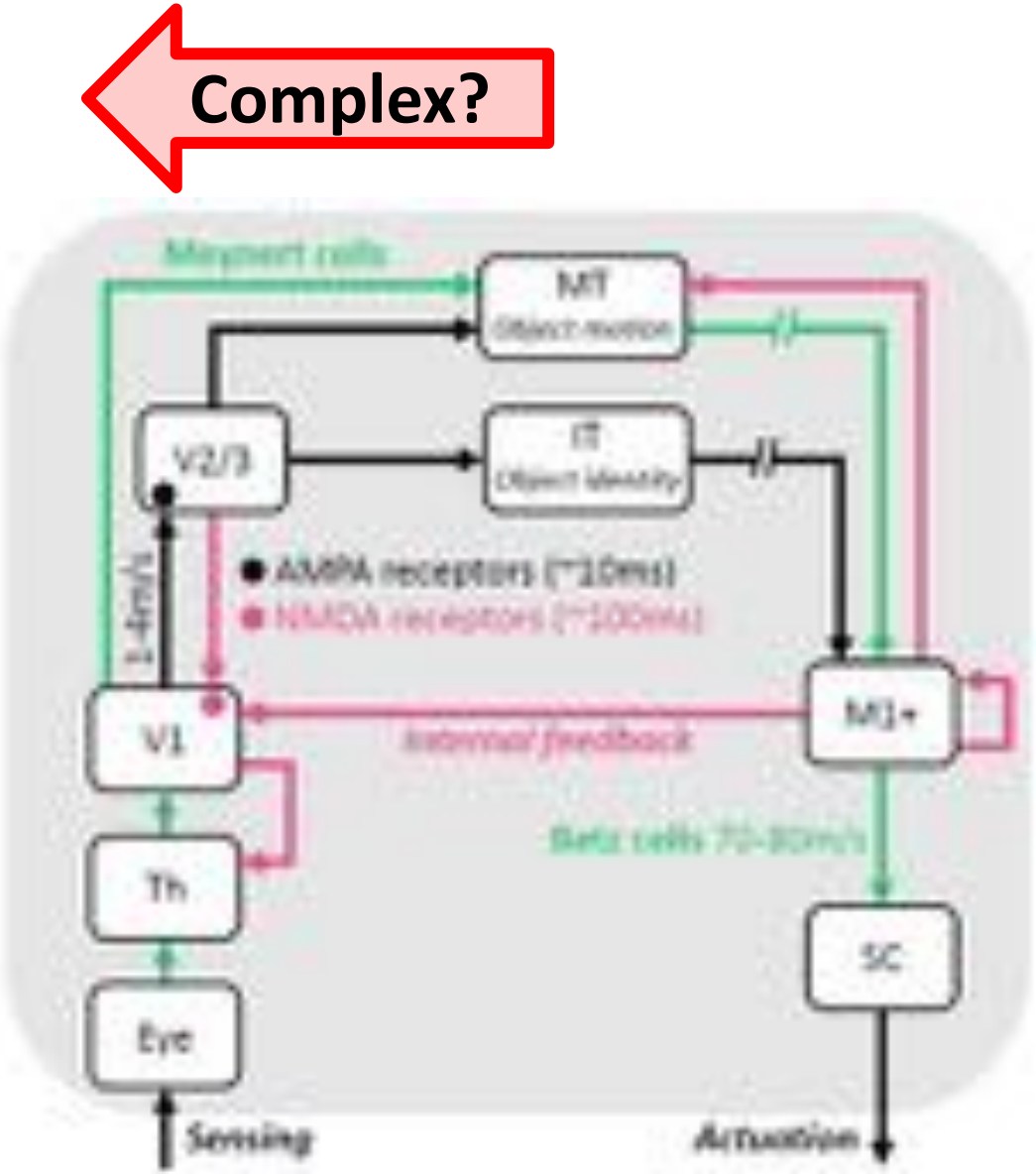
PNAS 2021

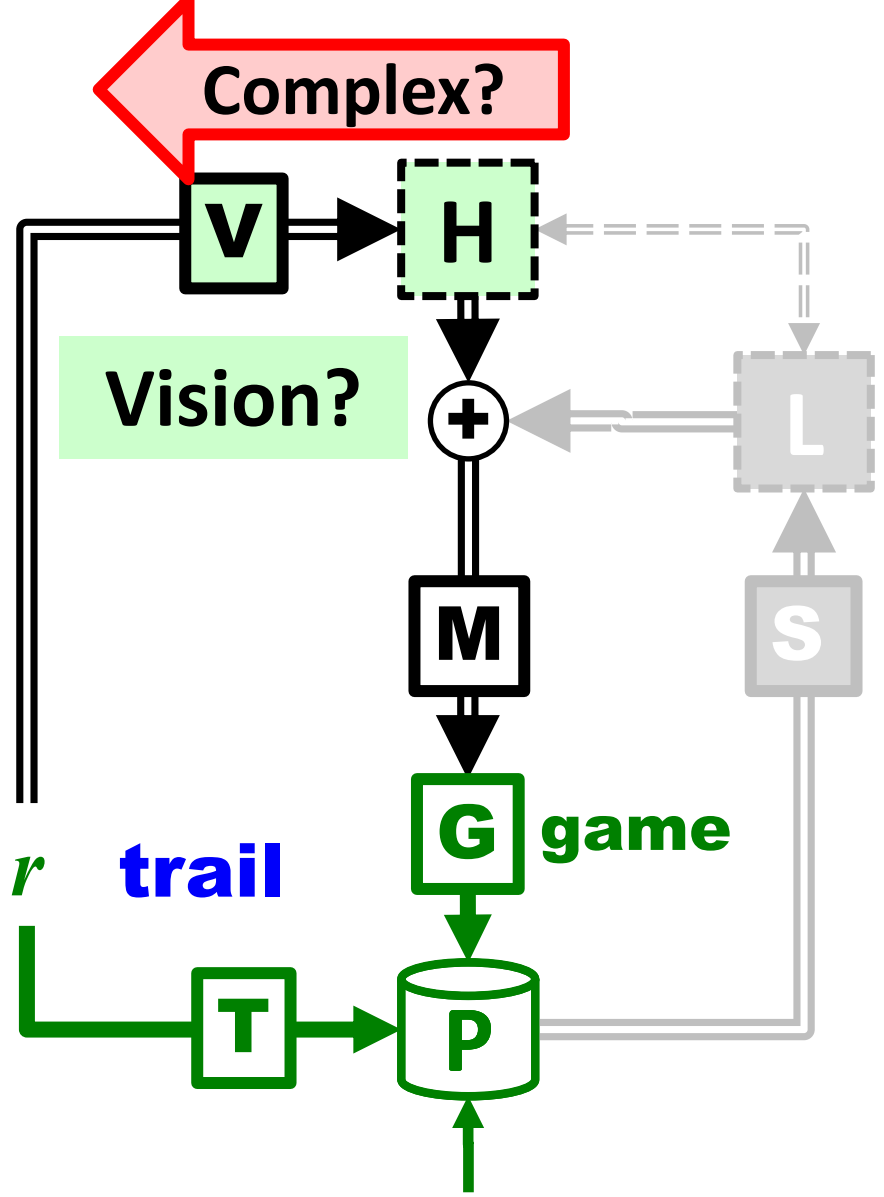


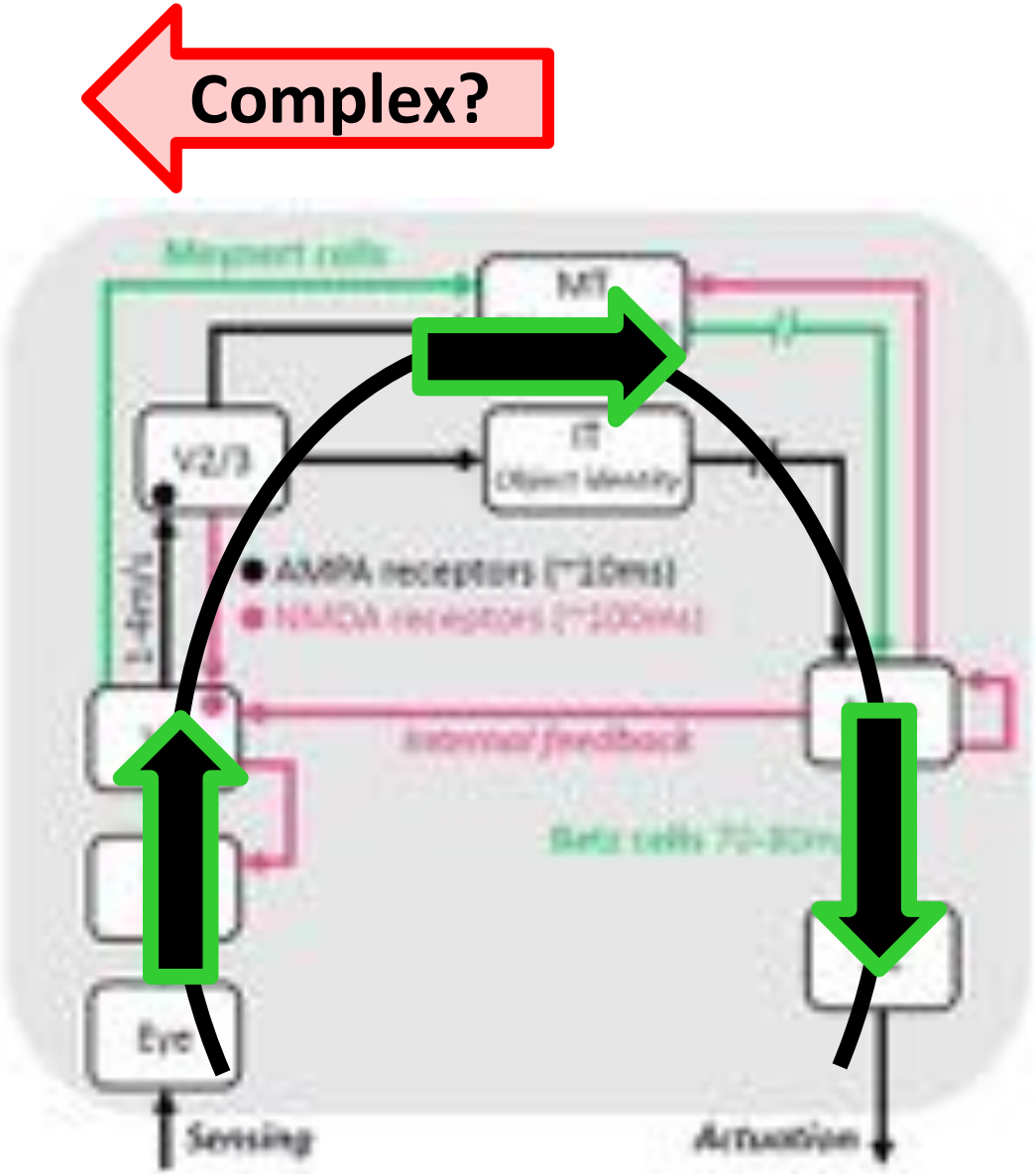
Layers

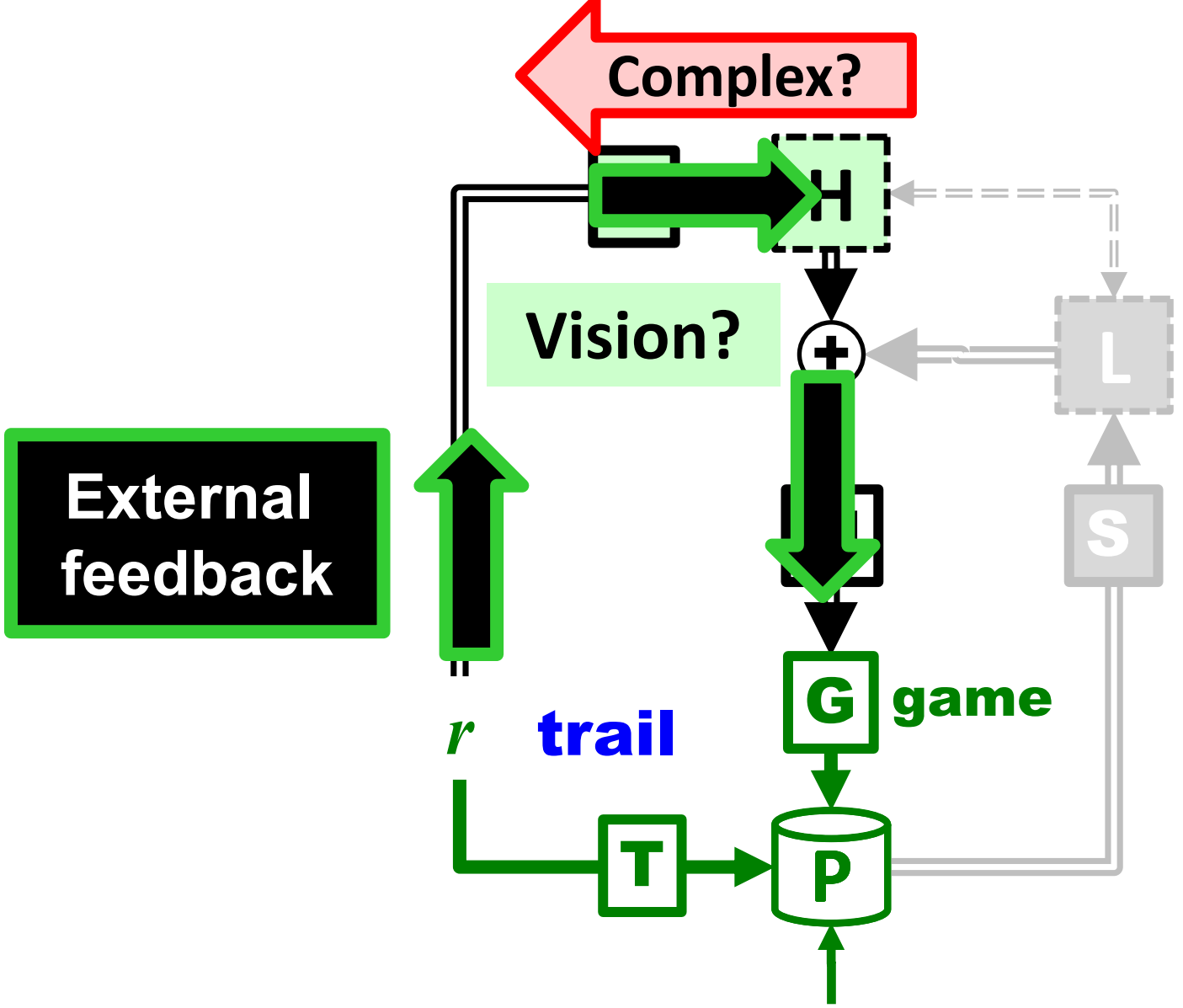
$$\delta\left(\begin{array}{c}\sum_{i=1}^{T}|a^{i-1}|+\\ |a^T|\left(2^{\lambda T}-|a|\right)^{-1}\end{array}\right)$$

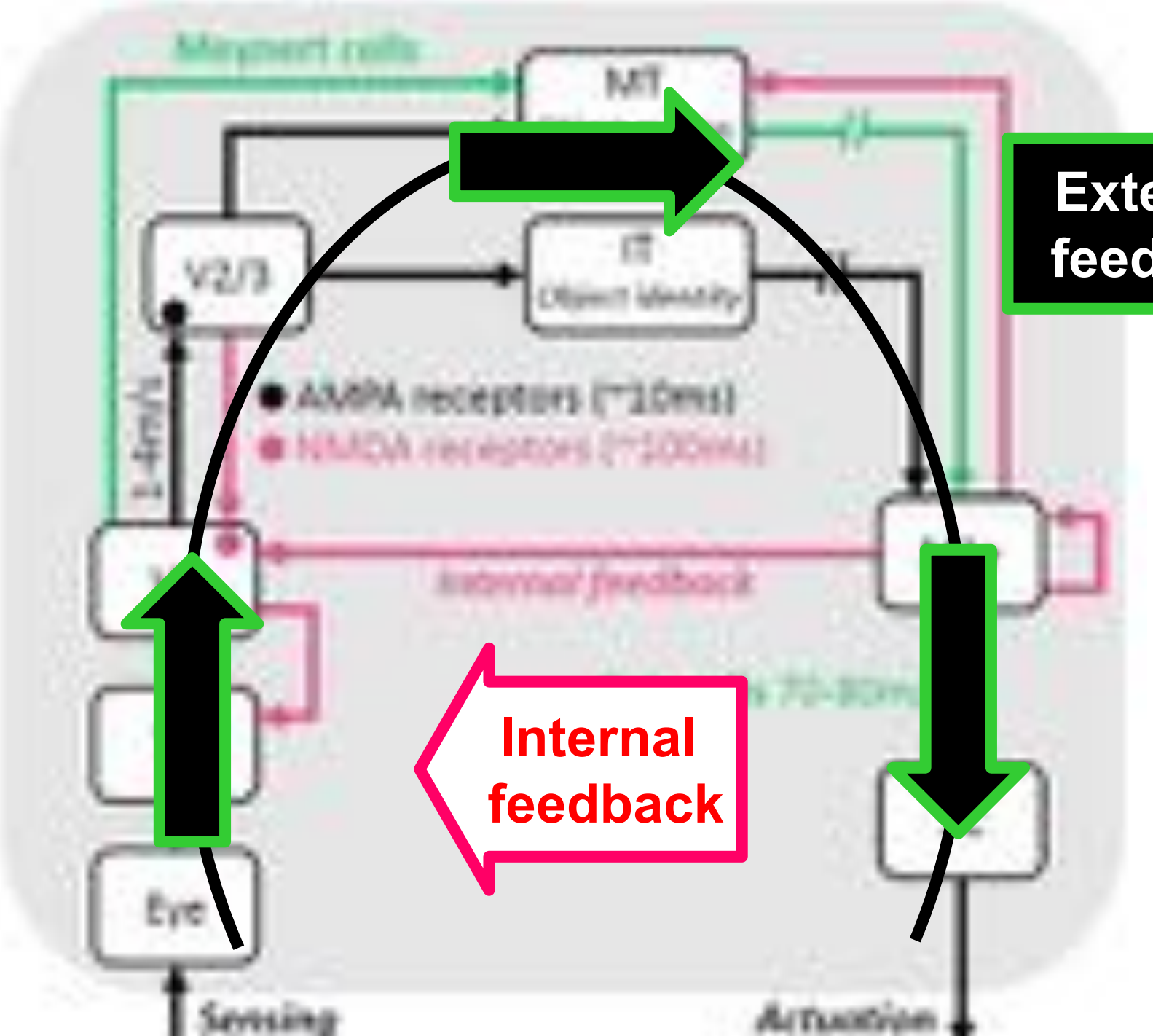



Complex?
MT
V2/3
IT
V1
M1+
Th
Eye
SC
Sensing
Actuation


Complex?
V
H
Vision?
L
M
S
G
game
r
trail
T
P


Complex?
MT
V2/3
IT
Eye
Sensing
Actuation


Complex?
H
Vision?
L
S
External feedback
G
game
r
trail
T
P



External feedback is standard from sensors to actuators.

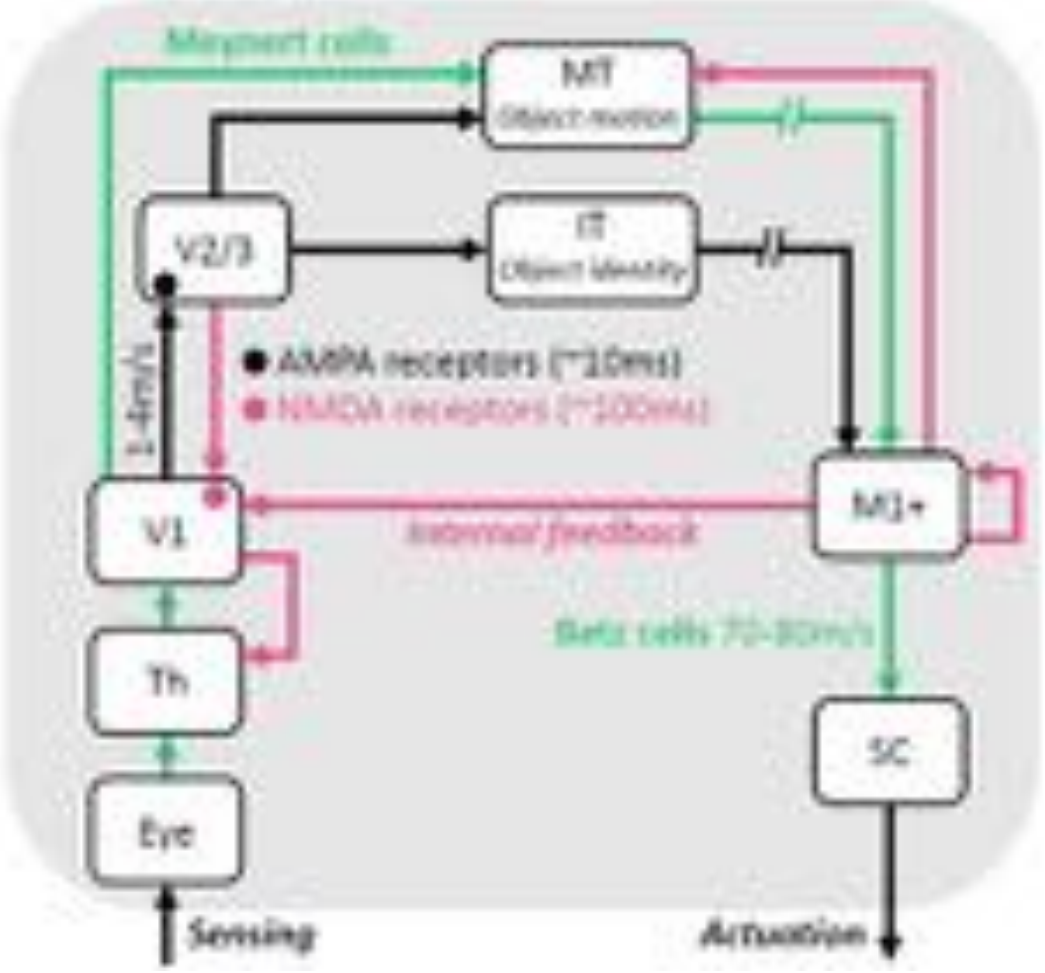
Internal feedback is more complex.

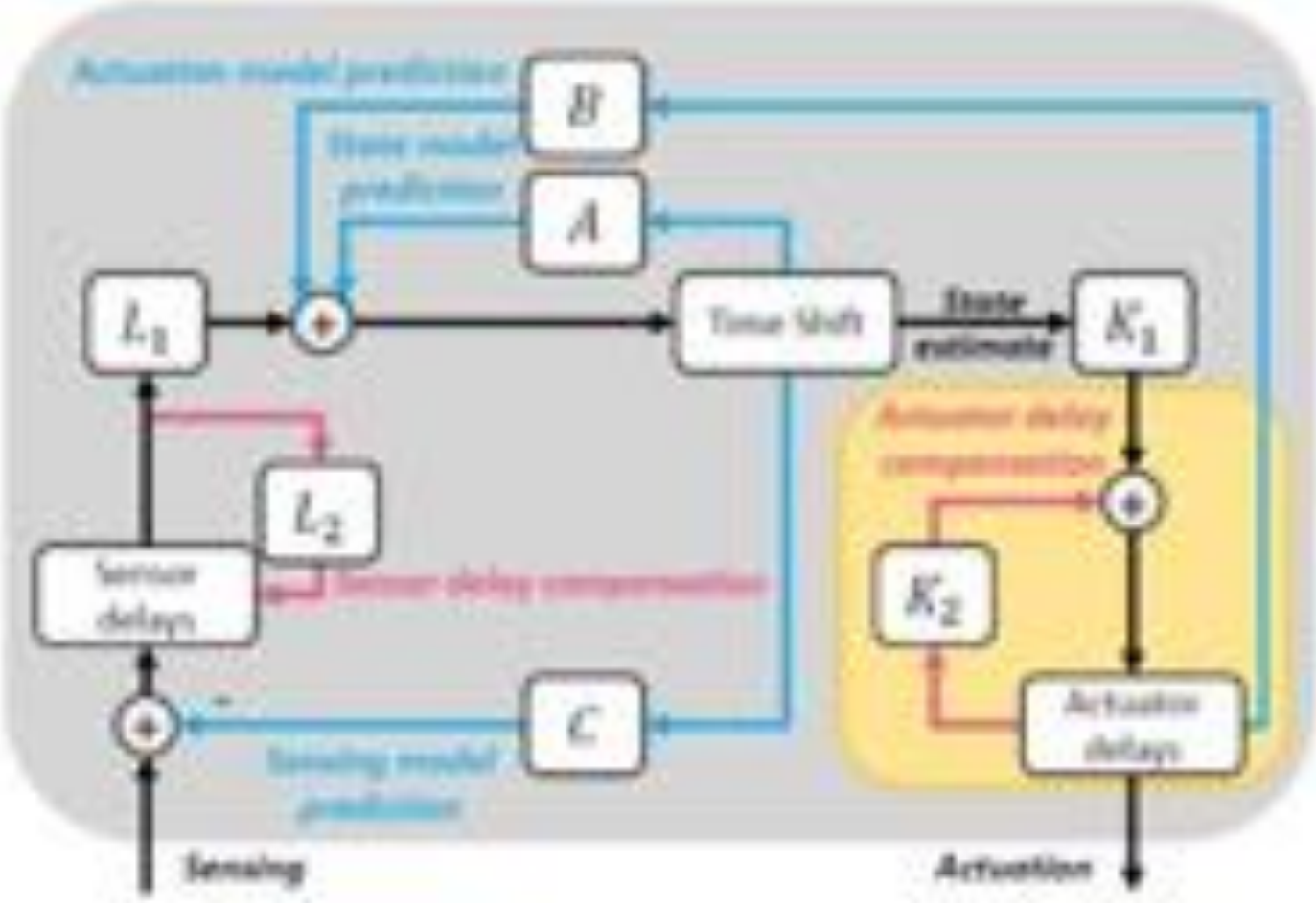
Dominated by internal delays.

Internal feedback in the cortical perception-action loop enables fast and accurate behavior

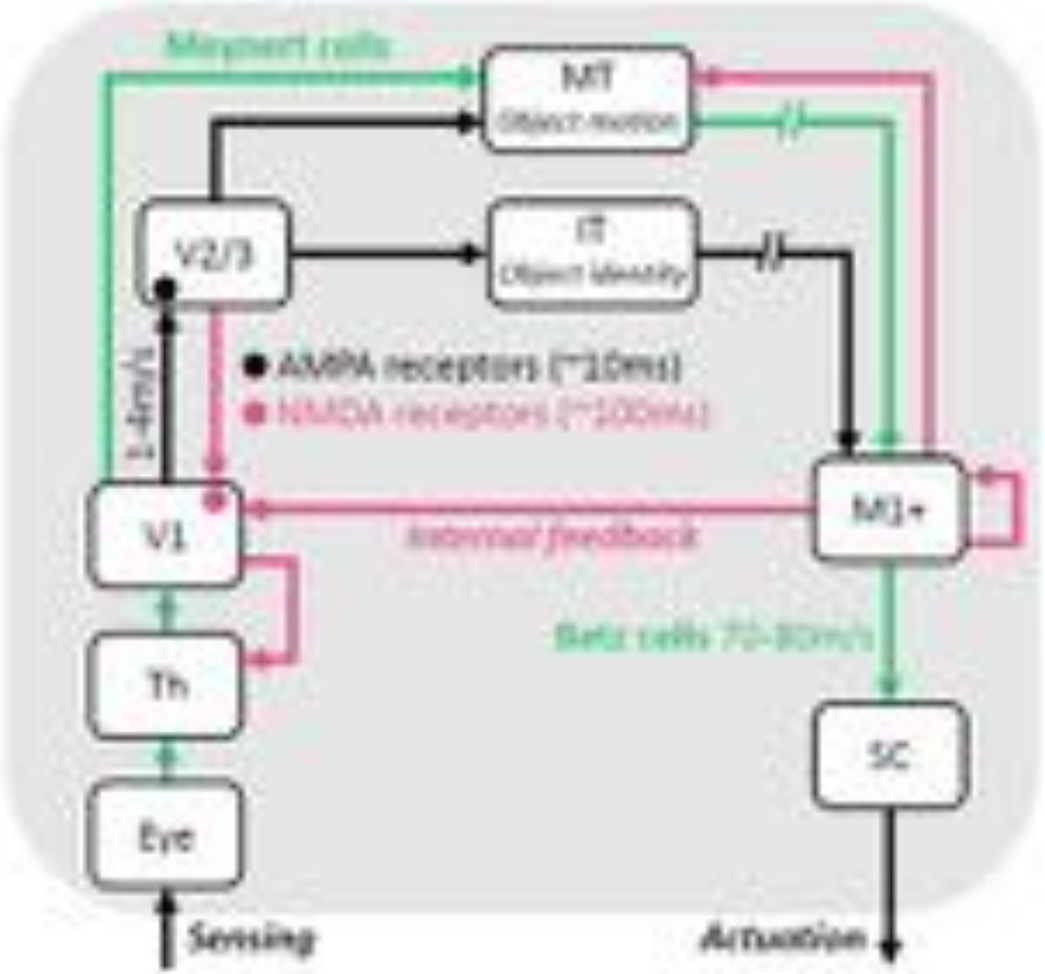
Jing Shuang (Lisa) Li[a,1], Anish A. Sarma[a,b,1], Terrence J. Sejnowski[c,d], and John C. Doyle[a]

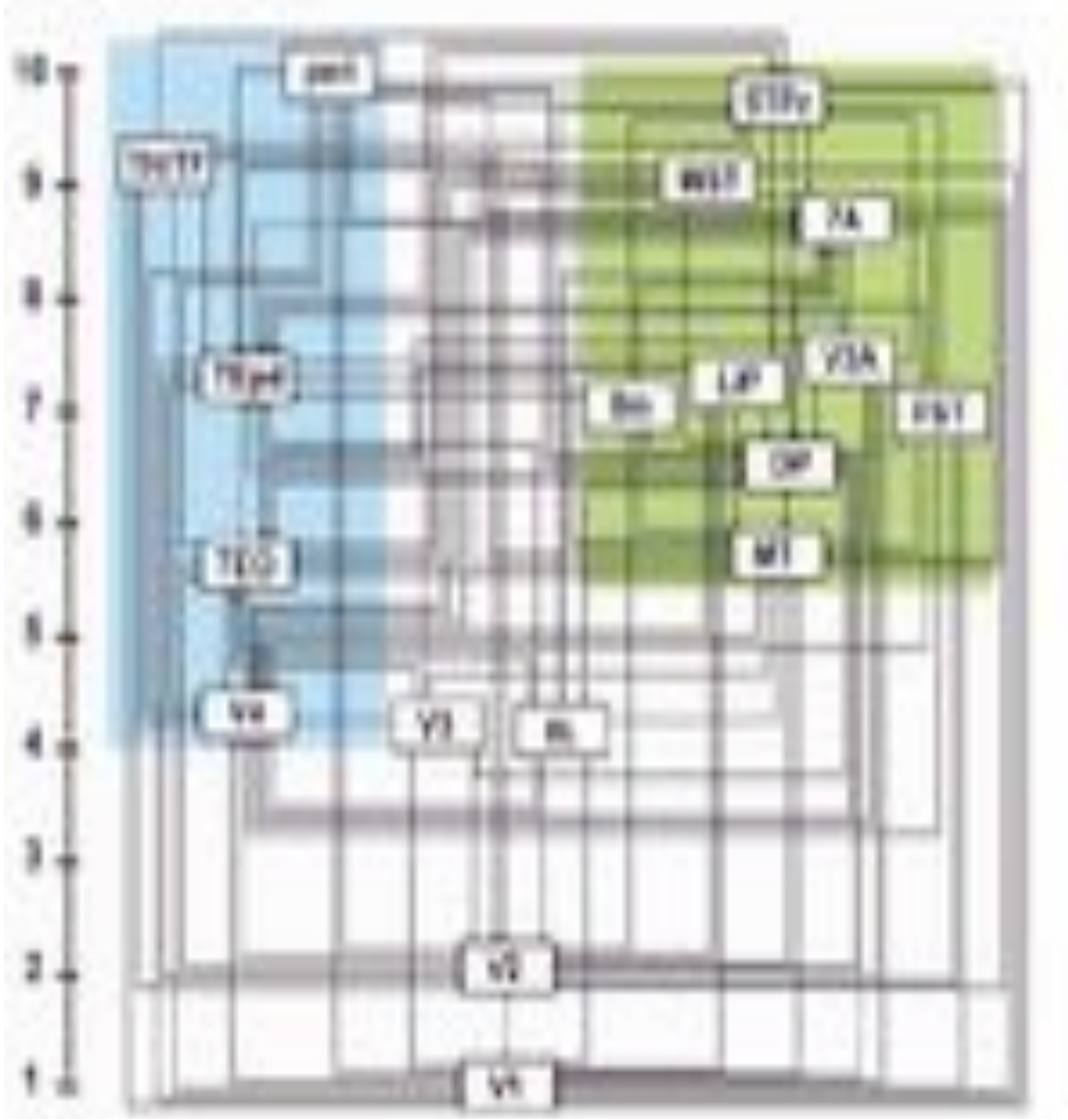
PNAS 2023





Layers

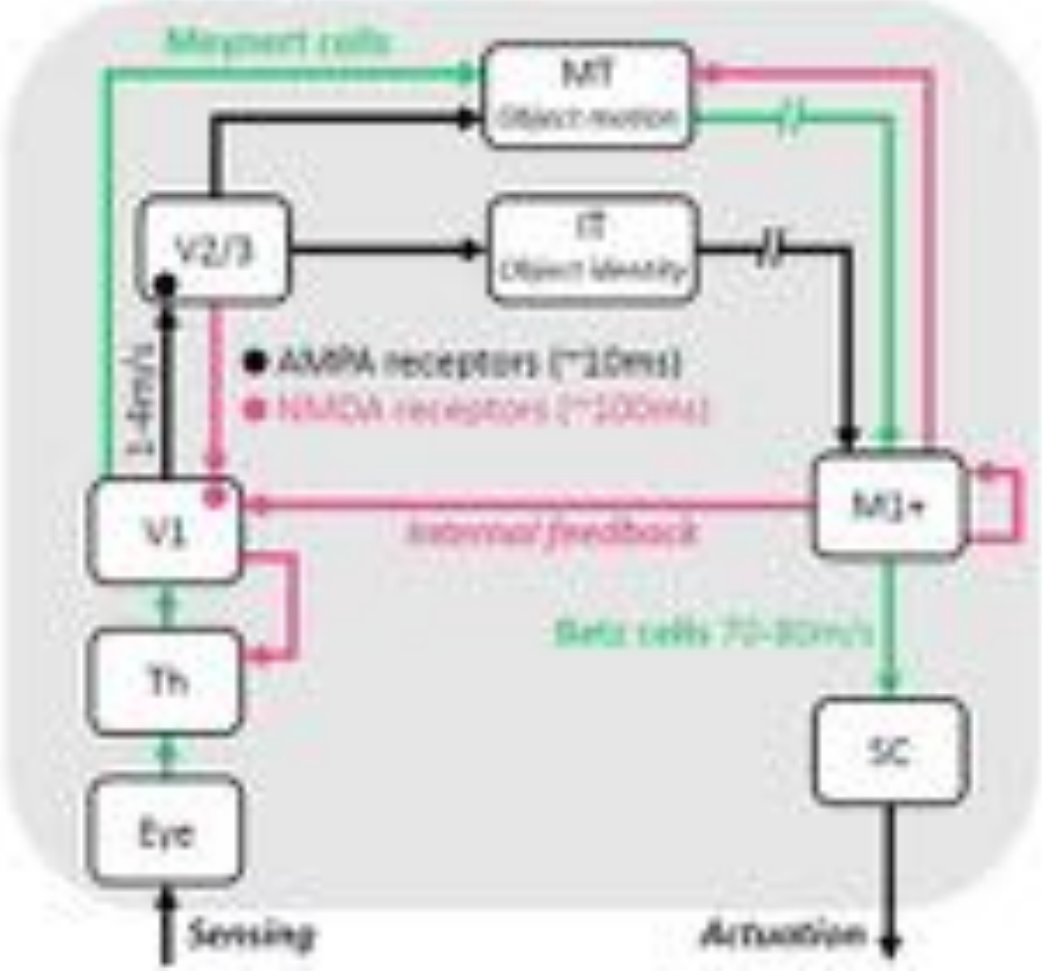


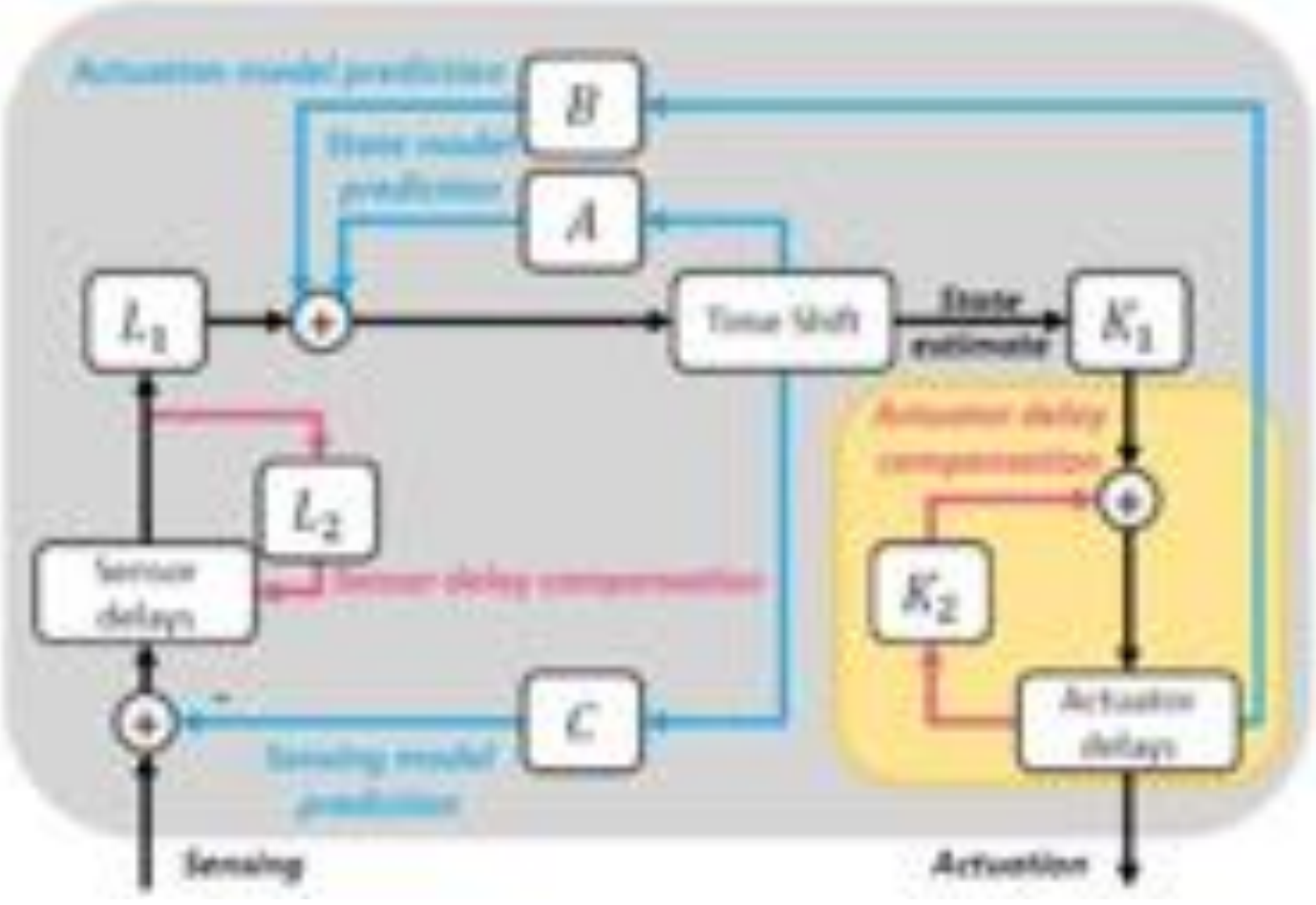


Felleman & Van Essen, 1991

Internal feedback in the cortical perception-action loop enables fast and accurate behavior

Jing Shuang (Lisa) Li[a,1], Anish A. Sarma[a,b,1], Terrence J. Sejnowski[c,d], and John C. Doyle[a]



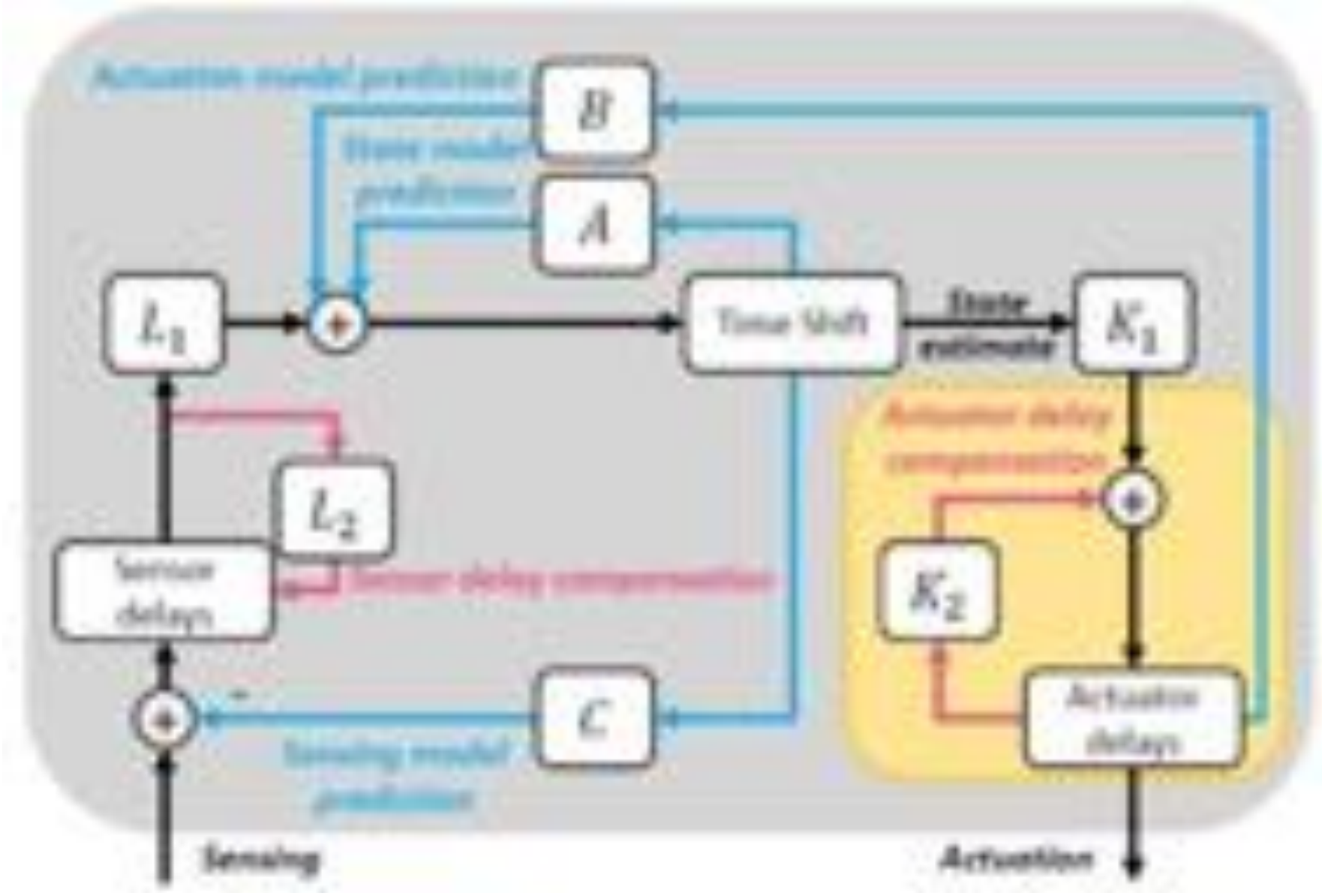


Delays in blue signals?

Needs SLS

Beyond Bayes and Kalman

Unneeded in most engineering with fast electronics

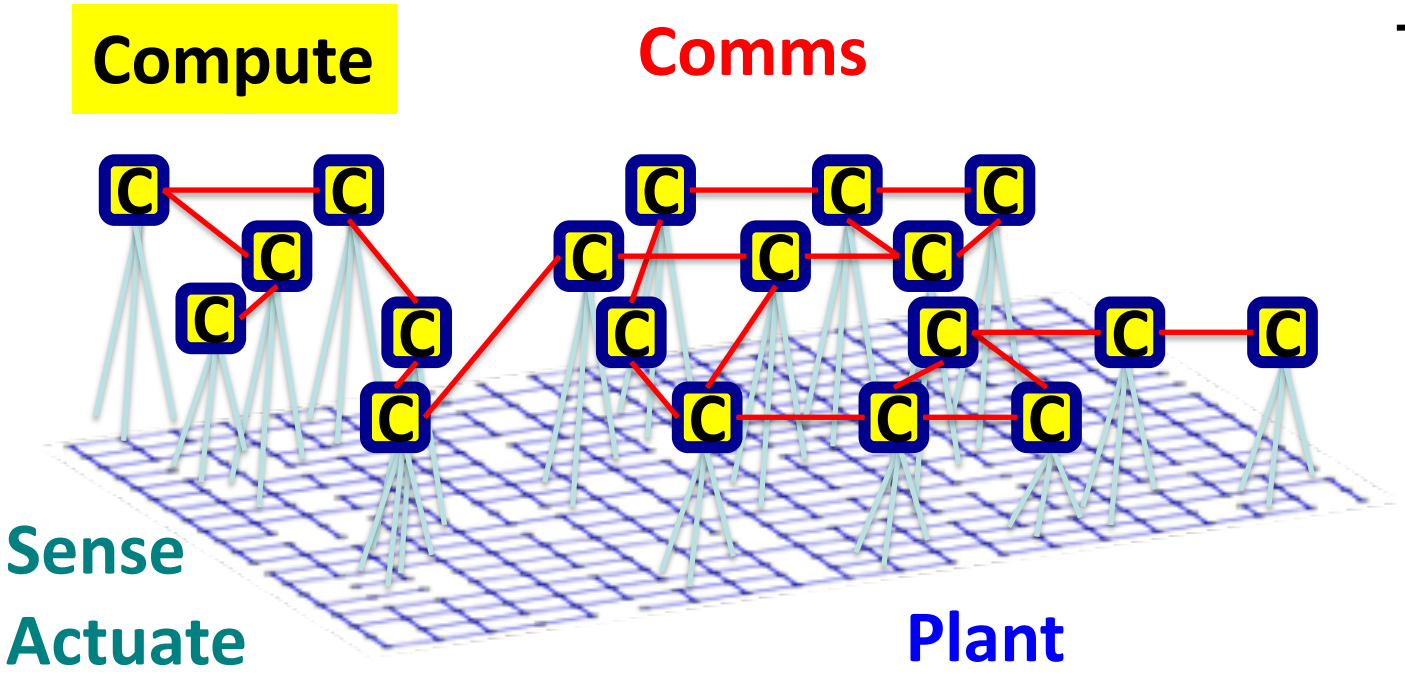


System Level Synthesis

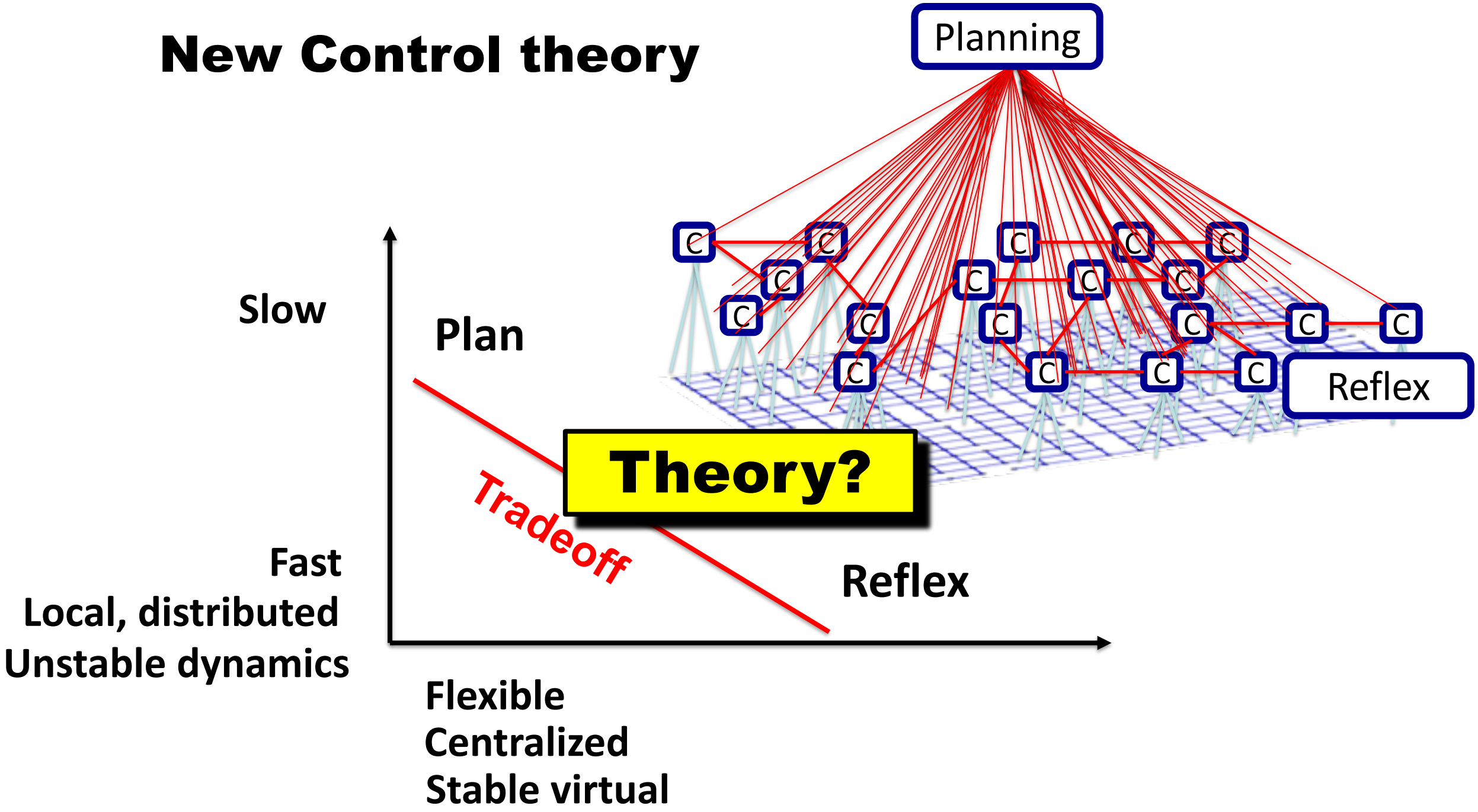
Sparse
Delayed
Quantized

Control

Sense
Comms
Compute
Actuate
Plant



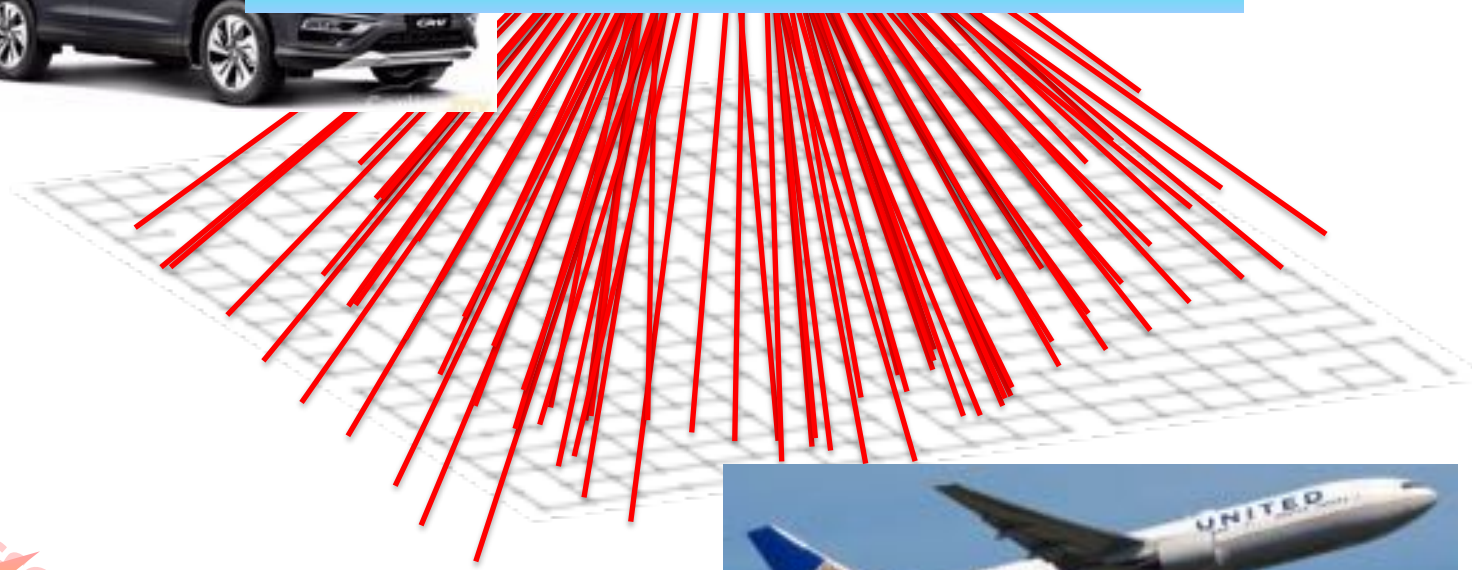
New Control theory



Control

Controller

Cheap fast electronics



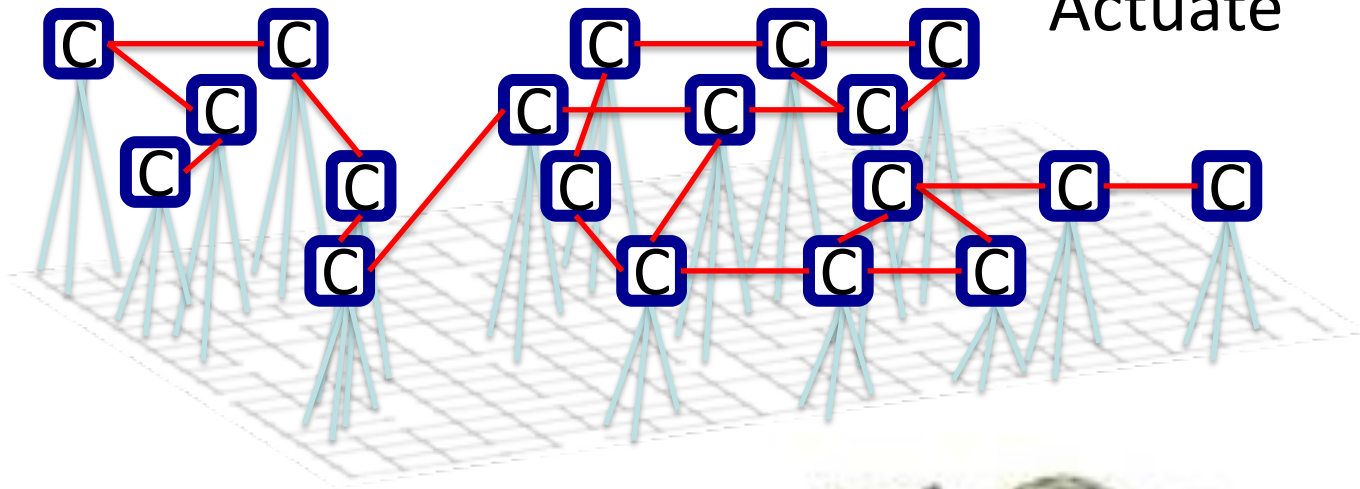
Fast

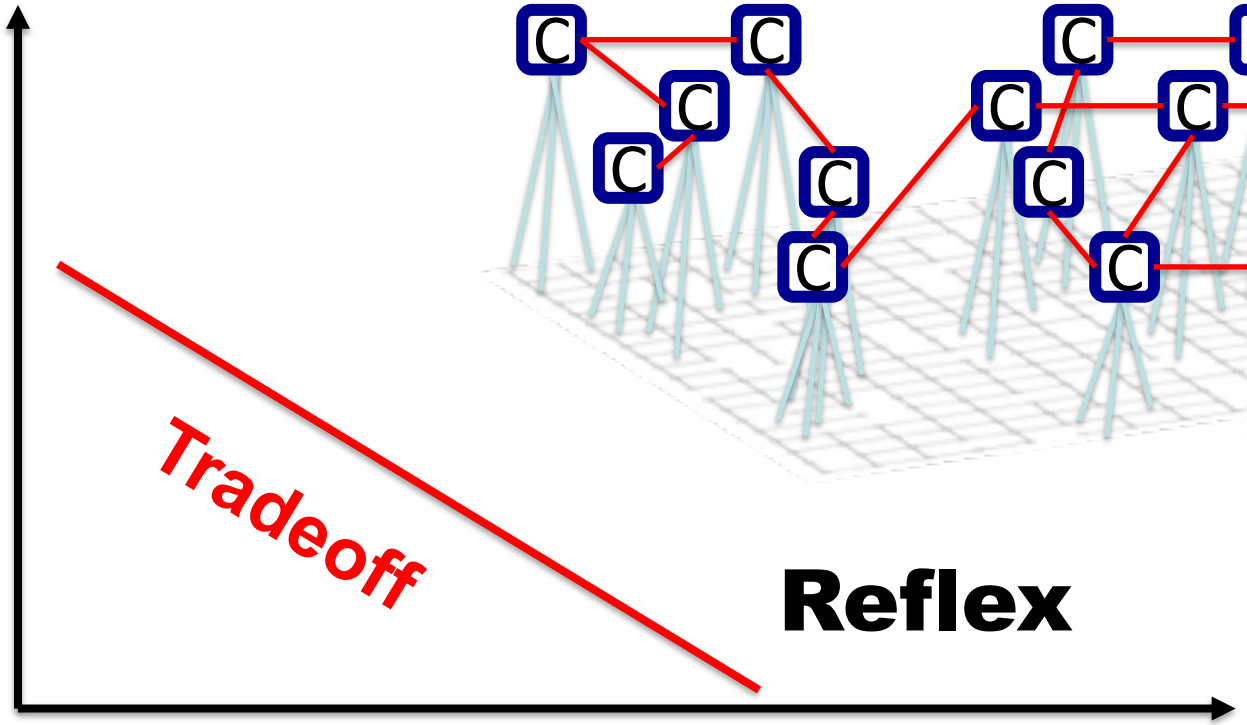
Flexible
Centralized
~~Stable~~ virtual

Cheap slow biology

Sparse
Delayed
Quantized

Sense
Comms
Compute
Actuate

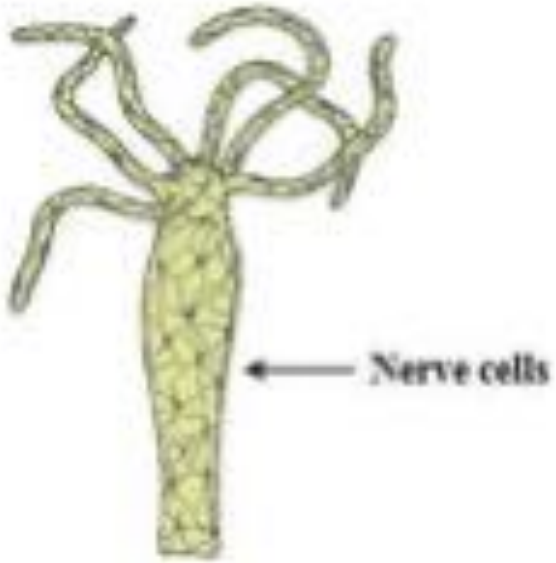


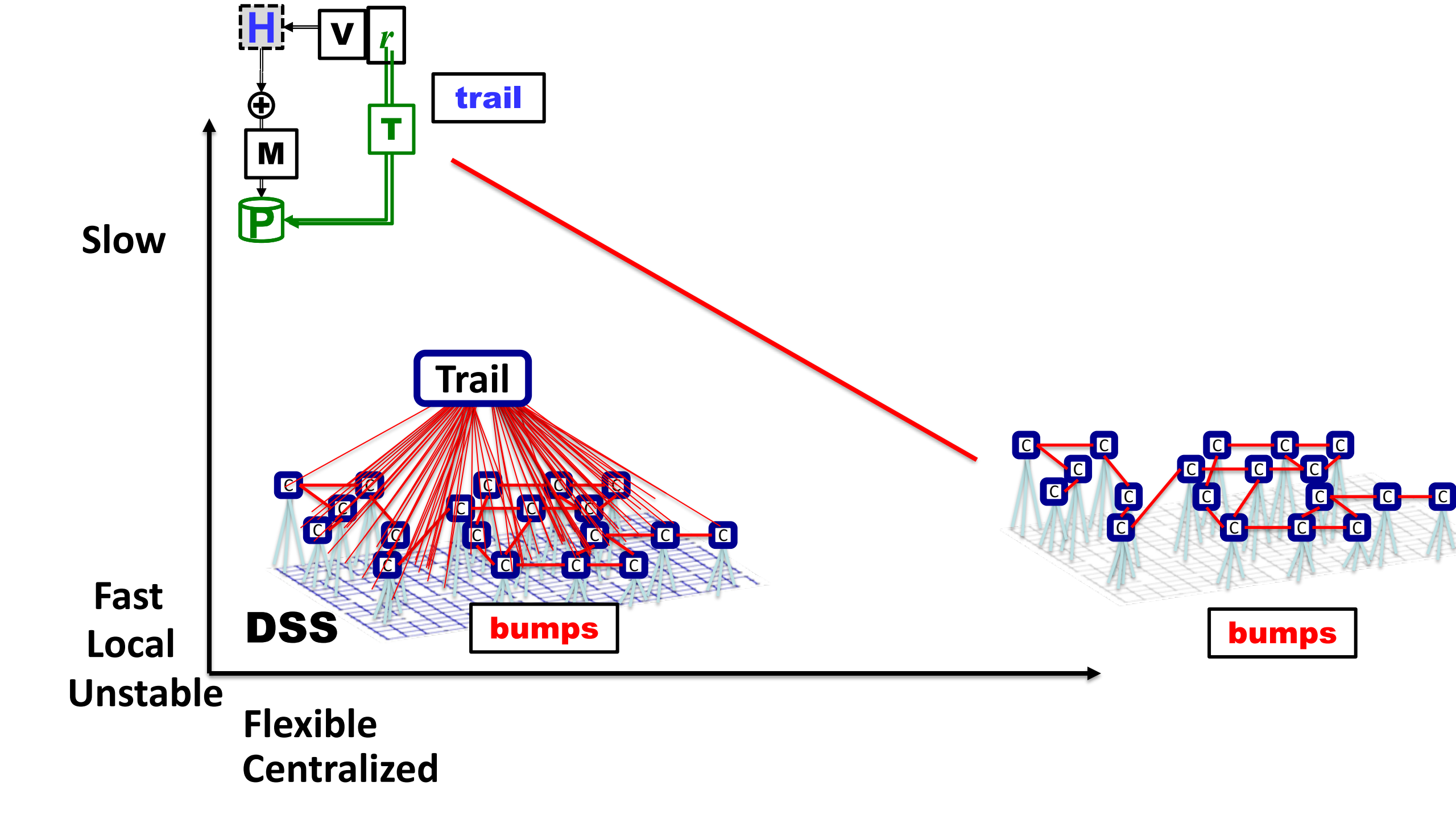


Fast

Local, distributed

Unstable dynamics



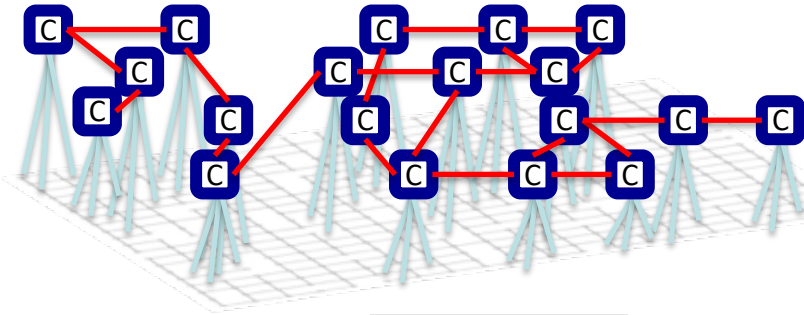

H
V
r
trail
T
M
P
Slow
Trail
bumps
DSS
bumps
Fast
Local
Unstable
Flexible
Centralized

Slow

Fast
Local
Unstable

Flexible
Centralized

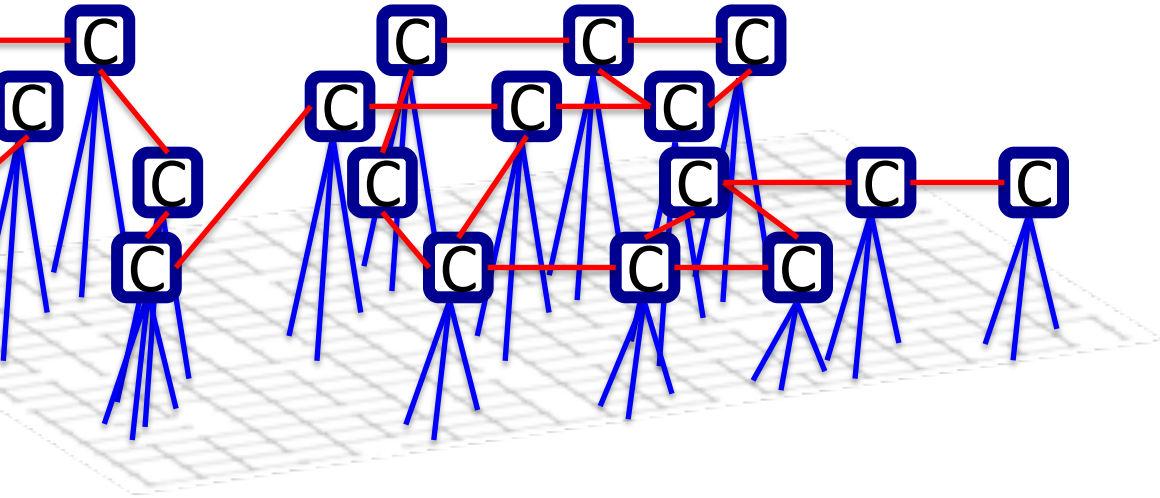
Current focus



bumps

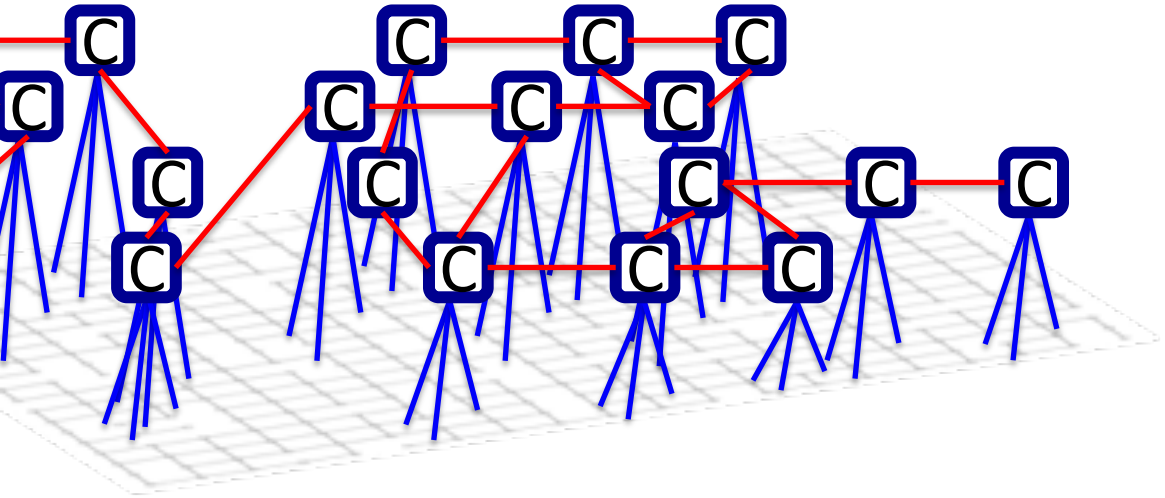
Everything:

- **Sparse**
- **Delayed**



Everything:

- **Sparse**
- **Delayed**
- **Layered**



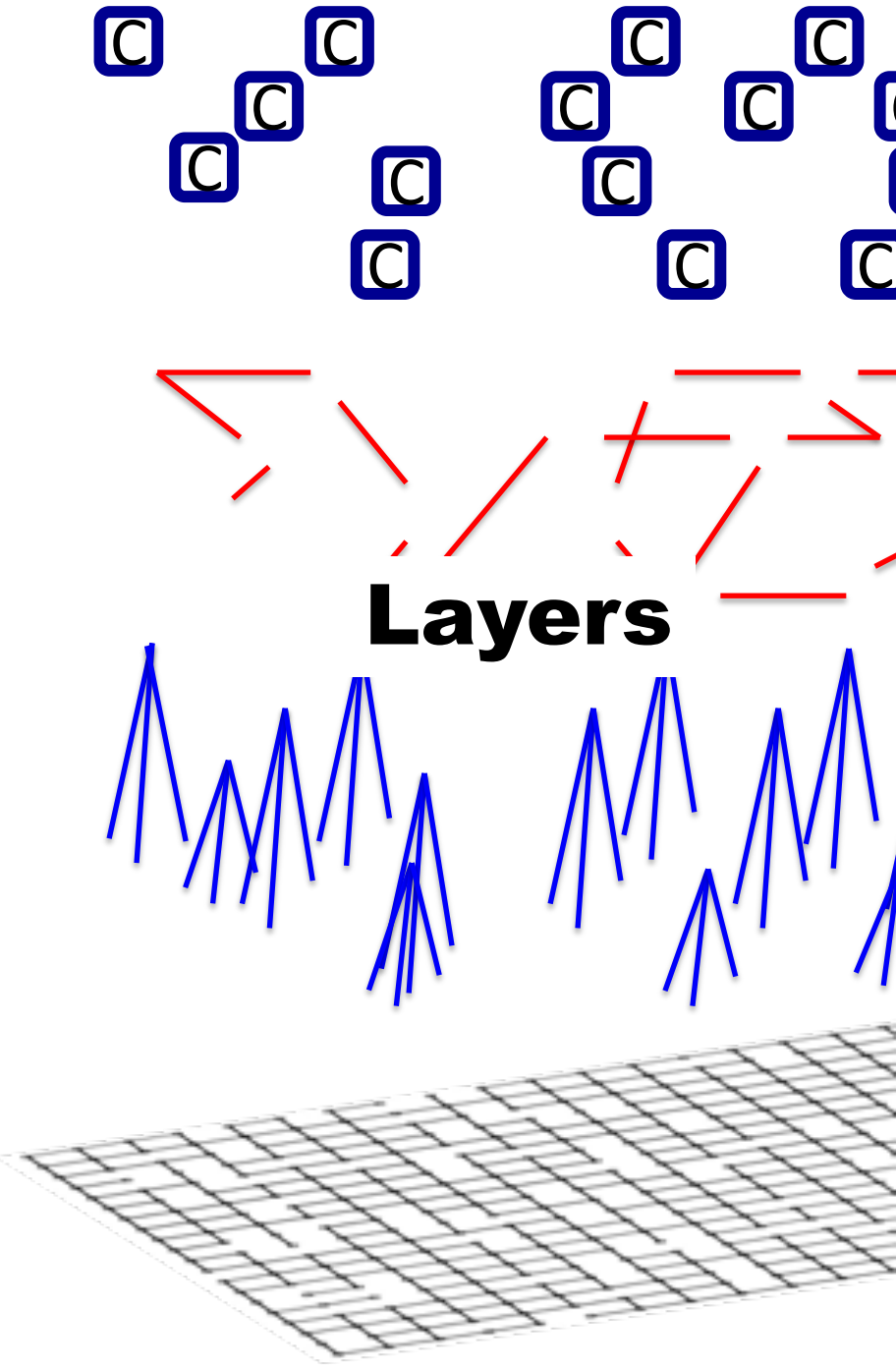
Compute

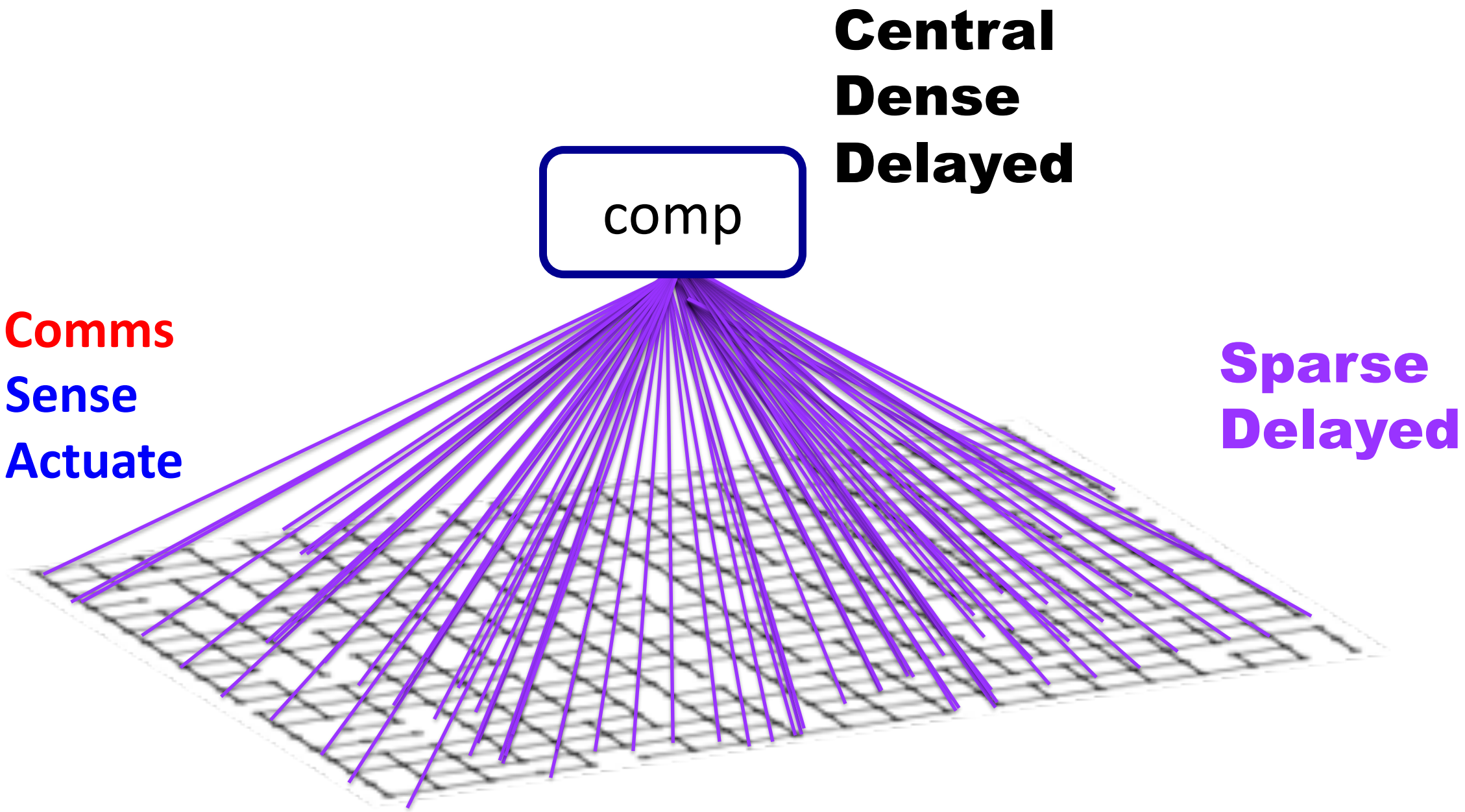
Comms

Sense

Actuate

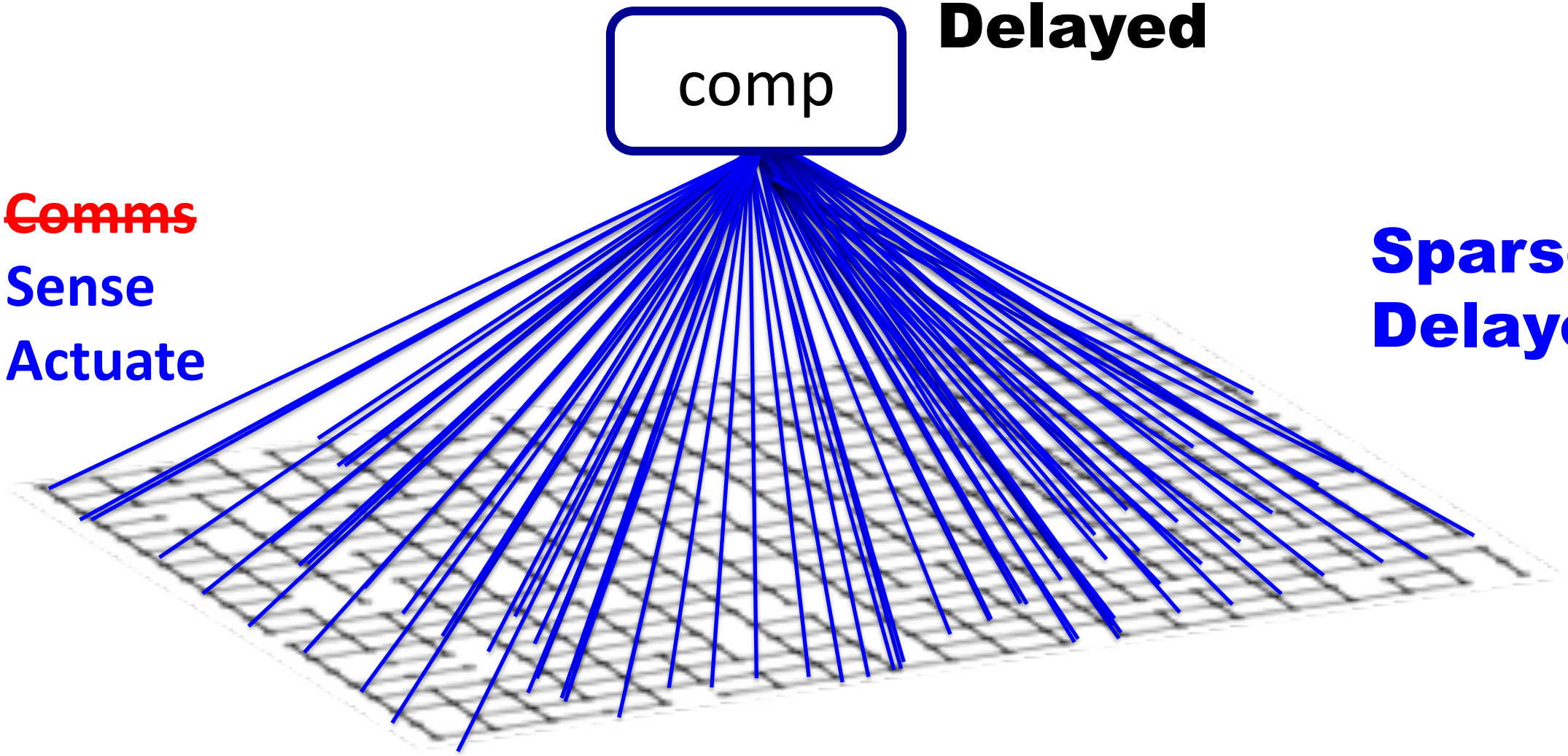
Plant




Central
Dense
Delayed
comp
Comms
Sense
Actuate
Sparse
Delayed

Comms modeled
as if in sense/act

Central
Dense
Delayed

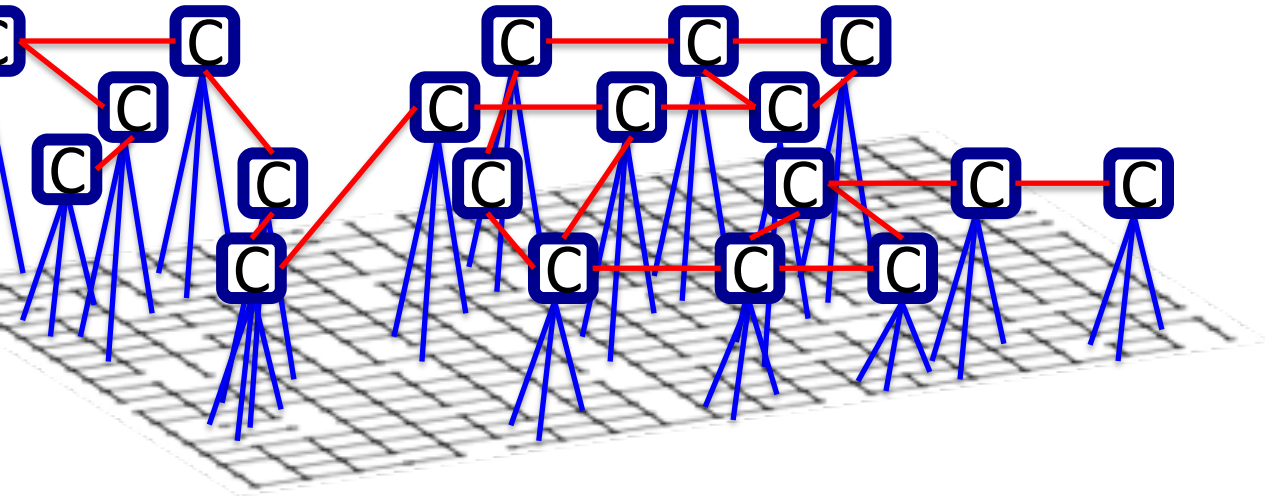


~~Comms~~
Sense
Actuate

Sparse
Delayed

Everything:

- **Sparse**
- **Delayed**

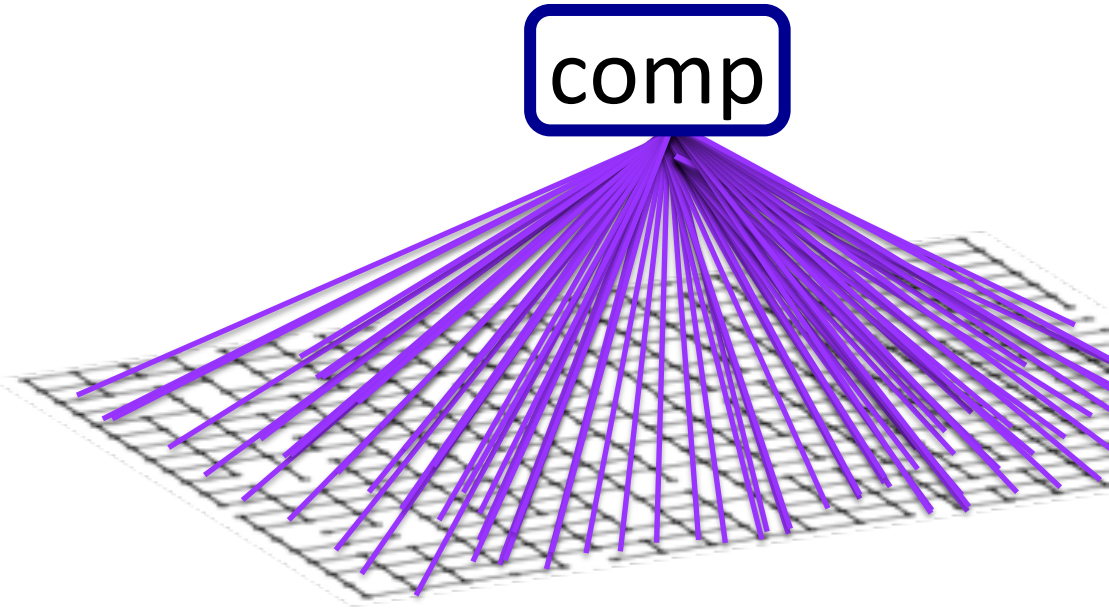


Need SLS

Previously intractable.

Sense&Act

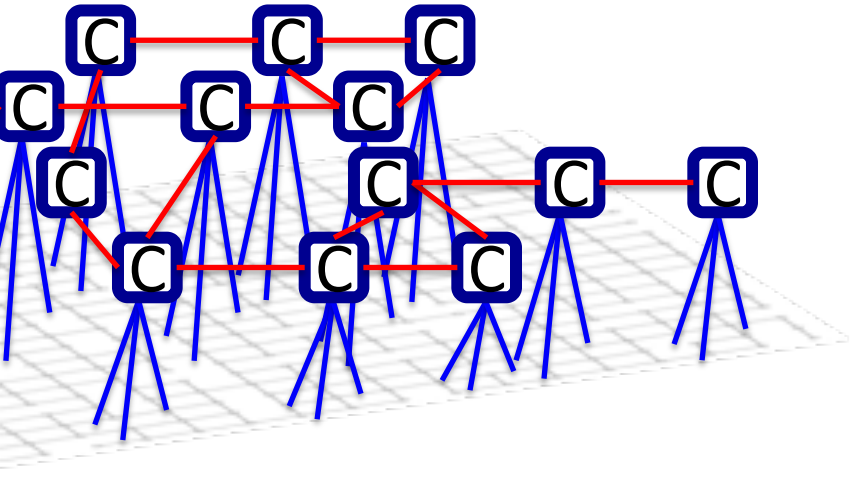
- **Sparse**
- **Delayed**



preSLS

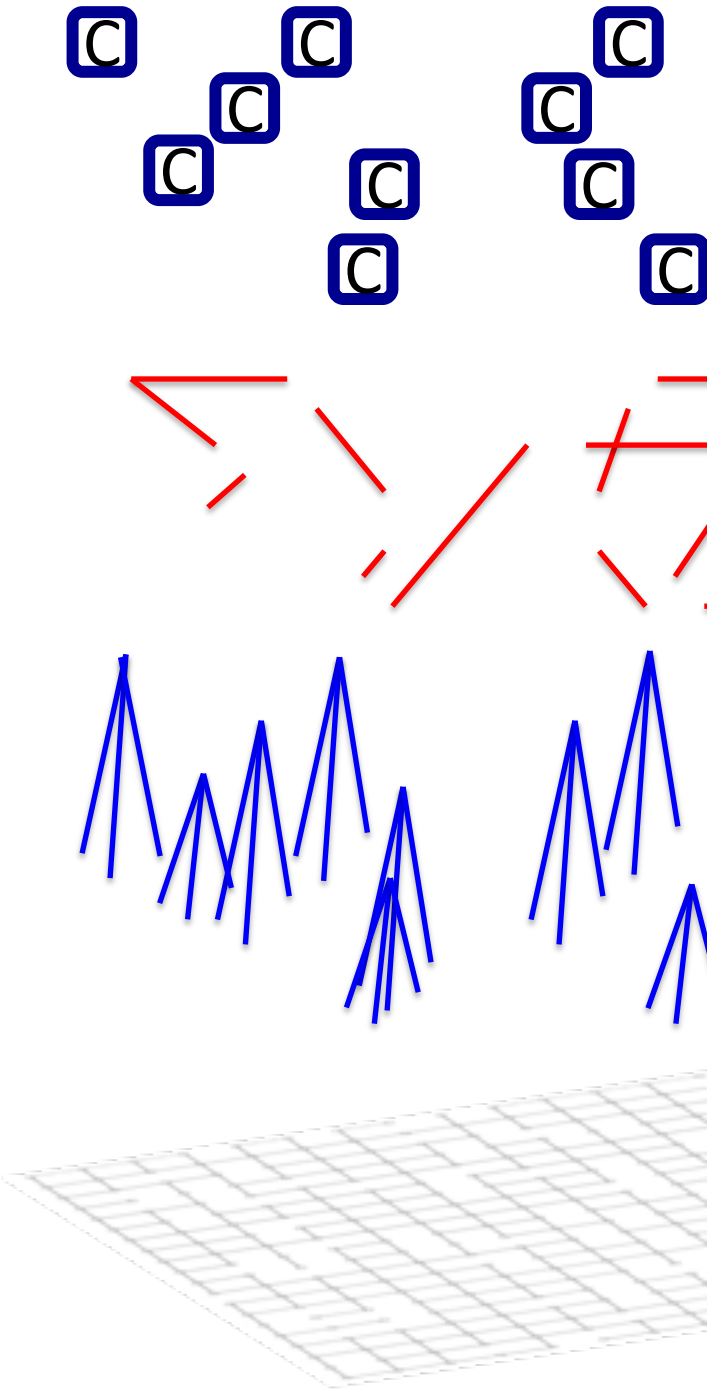
Can do more than we realized.

How does SLS work?



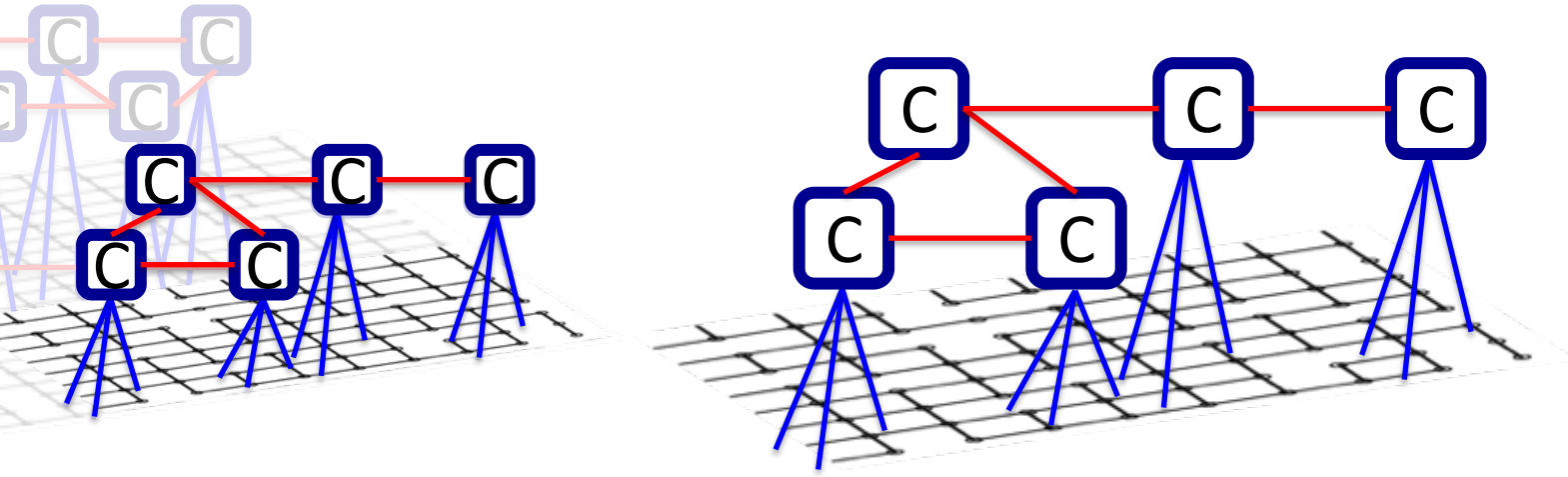
Need SLS

Layers

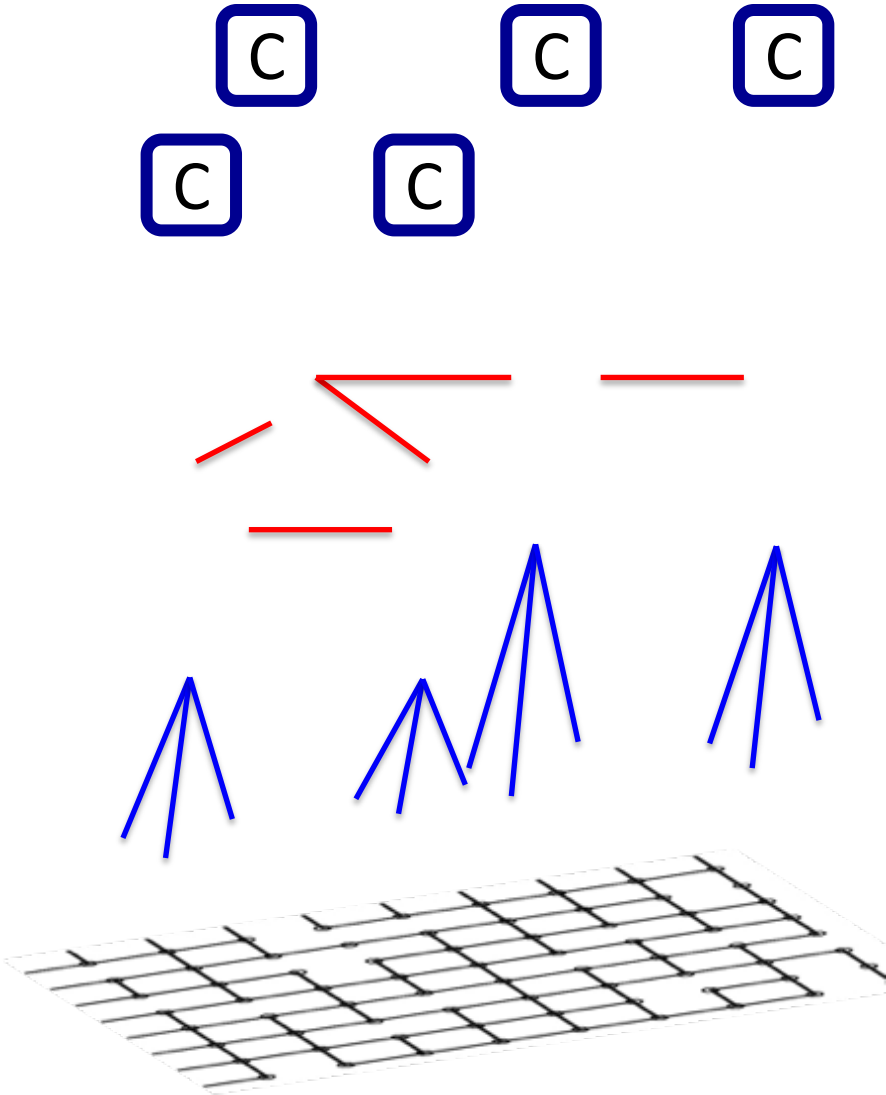


Layers

Zoom into a patch

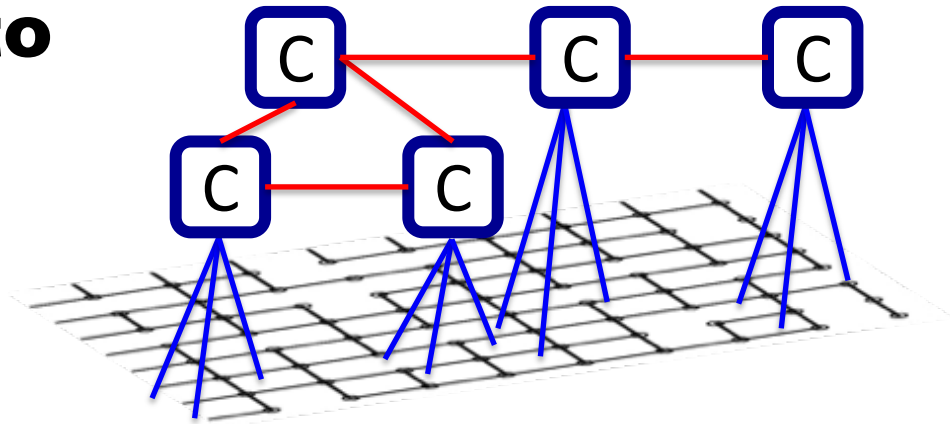


Patches are design choices



Think global, act local

Zoom into a patch



(Overlapping) Patches are design choices

Design/implement in patches with coordinated objectives

Scalable and implementable

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Review article

System level synthesis

James Anderson[a], John C. Doyle[a], Steven H. Low[a], Nikolai Matni[b,*]

[a] Department of Computing + Mathematical Sciences, California Institute of Technology, Pasadena CA, 91125, United States
[b] Department of Electrical Engineering and Computer Sciences UC Berkeley, Berkeley CA, 94720, United States