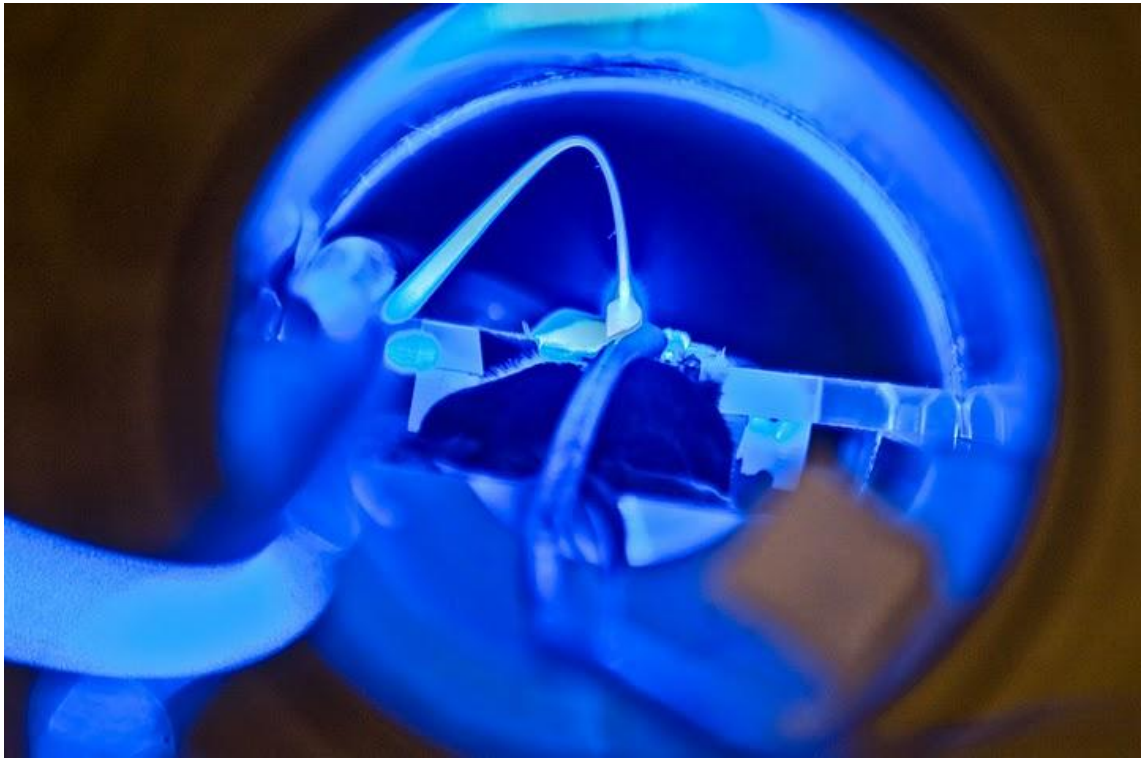
Jin’s OS?

Optogenetic fMRI (ofMRI)



Stimulate **specific cell types** with **temporal precision**.

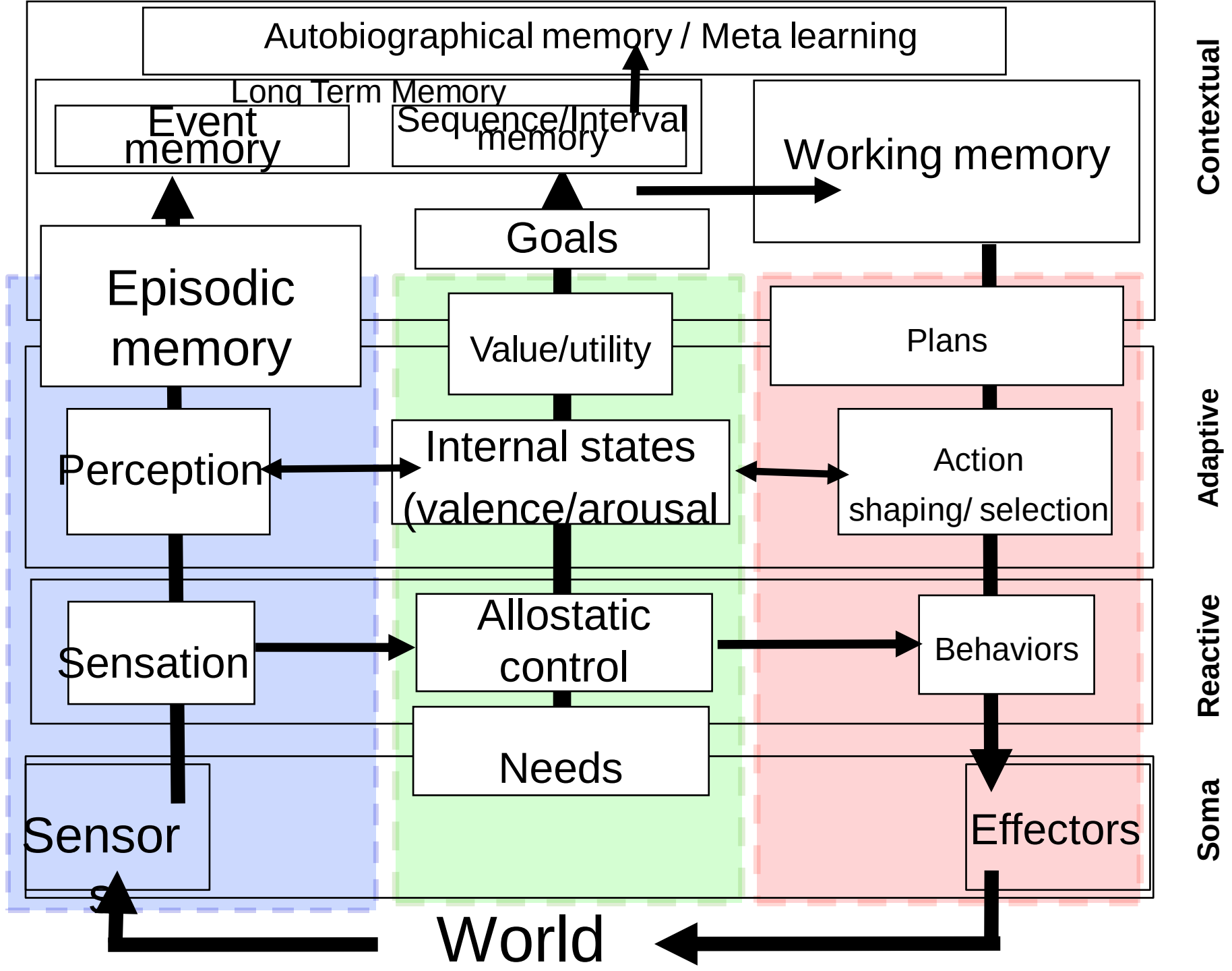
Monitor **causal**, ***in vivo***, and **brain-wide** activity responses.

Lee et al., Nature 2010

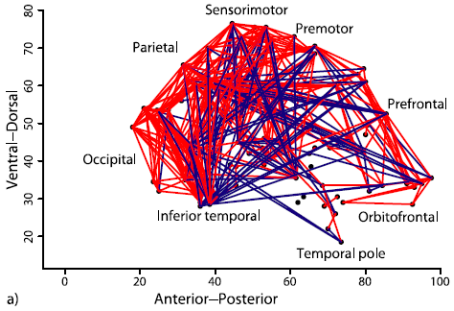
Issues

- Talks great, offline great, discussions weak
- Architecture? (Not much, really. It's hard.)
- $\Rightarrow$ Concrete, concrete, concrete
- OS as (dangerous!!!) metaphor

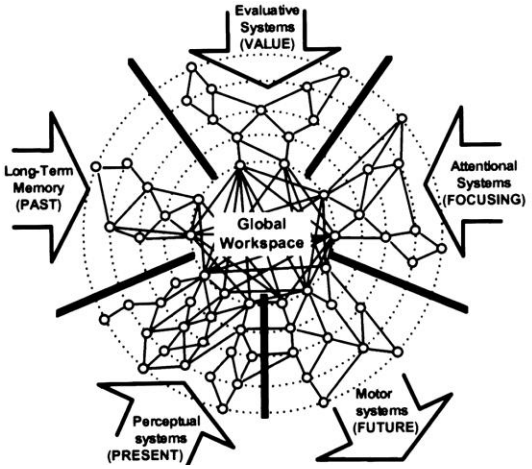
- Start with Ed
- End with Helen, Tony (pdf), and Paul


Autobiographical memory / Meta learning
Long Term Memory
Event memory
Sequence/Interval memory
Working memory
Goals
Episodic memory
Value/utility
Plans
Perception
Internal states (valence/arousal
Action shaping/ selection
Sensation
Allostatic control
Behaviors
Needs
Sensor s
Effectors
World
Contextual
Adaptive
Reactive
Soma

Cartoon interpretation of economical small-world architecture in terms of cognitive processes



High efficiency
Short path length
(Higher cost)



Integrated processes

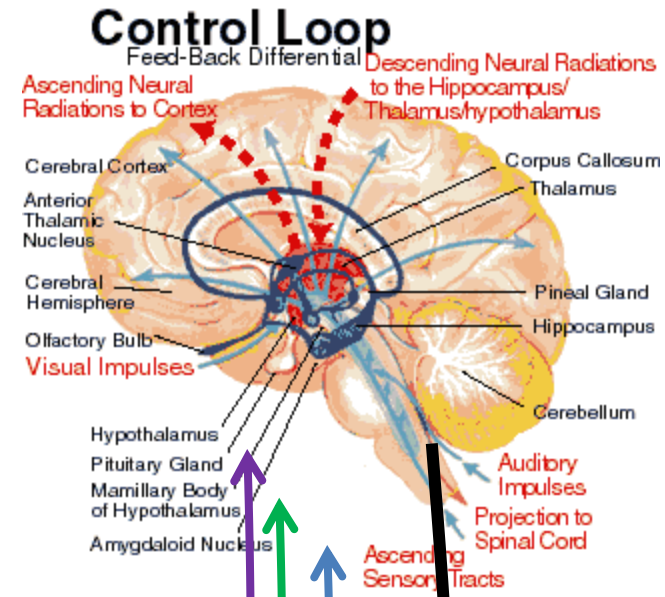
General – eg "executive"
Isotropic (IQ)
Distributed
Conscious
Effortful

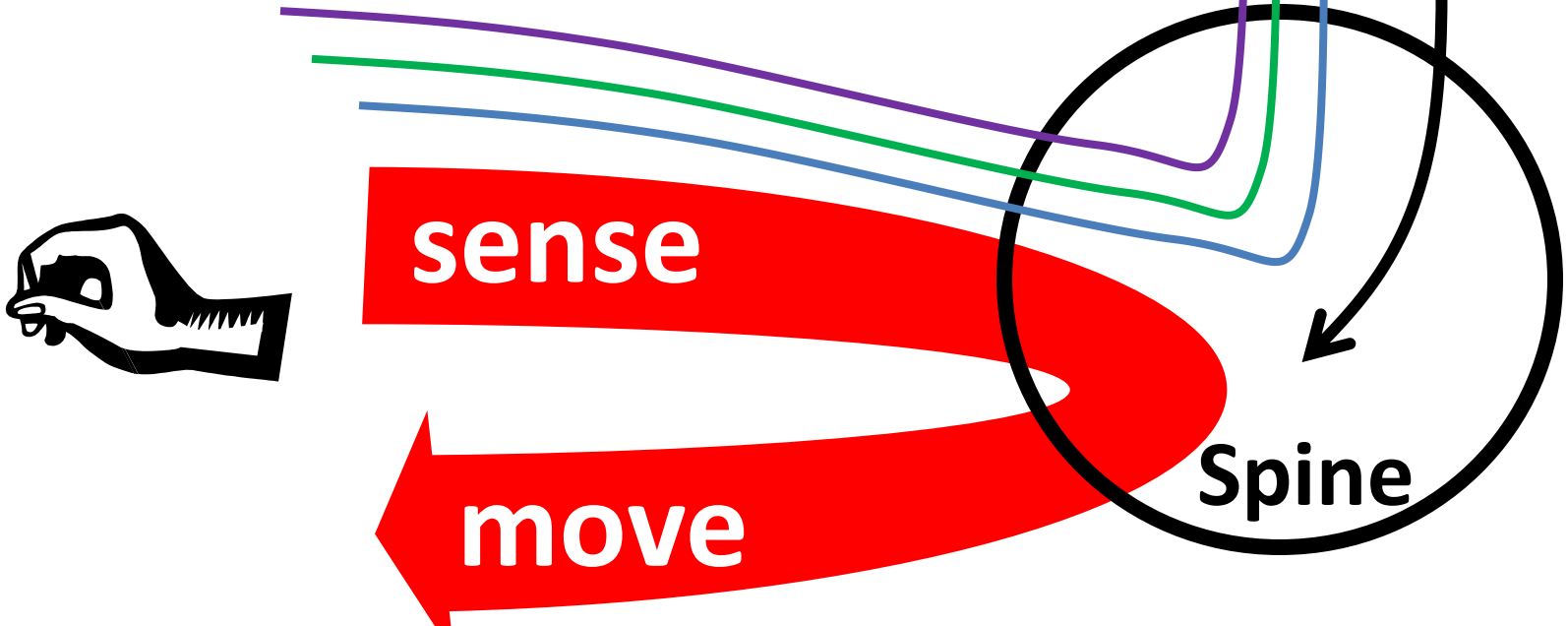
High clustering
Modularity
(Lower cost)

Segregated processes

Specialised – eg face vision
Encapsulated
Localised
Unconscious
Automatic

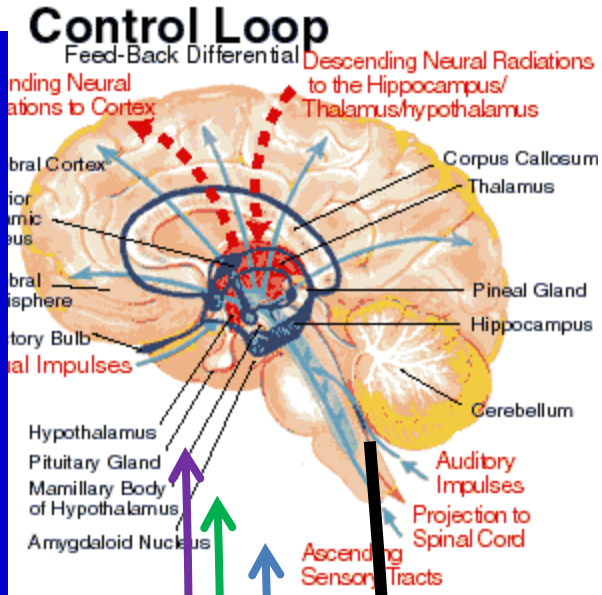
Why?

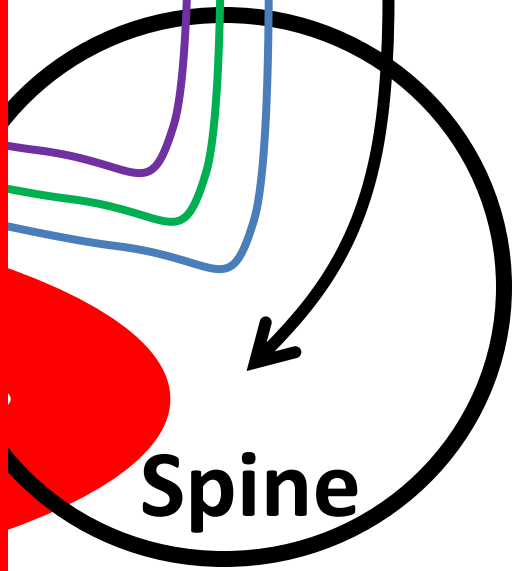

Control Loop
Feed-Back Differential
Ascending Neural Radiations to Cortex
Descending Neural Radiations to the Hippocampus/ Thalamus/hypothalamus
Cerebral Cortex
Corpus Callosum
Thalamus
Anterior Thalamic Nucleus
Cerebral Hemisphere
Pineal Gland
Hippocampus
Olfactory Bulb
Visual Impulses
Cerebellum
Hypothalamus
Pituitary Gland
Mamillary Body of Hypothalamus
Amygdaloid Nucleus
Auditory Impulses
Projection to Spinal Cord
Ascending Sensory Tracts


sense
move
Spine

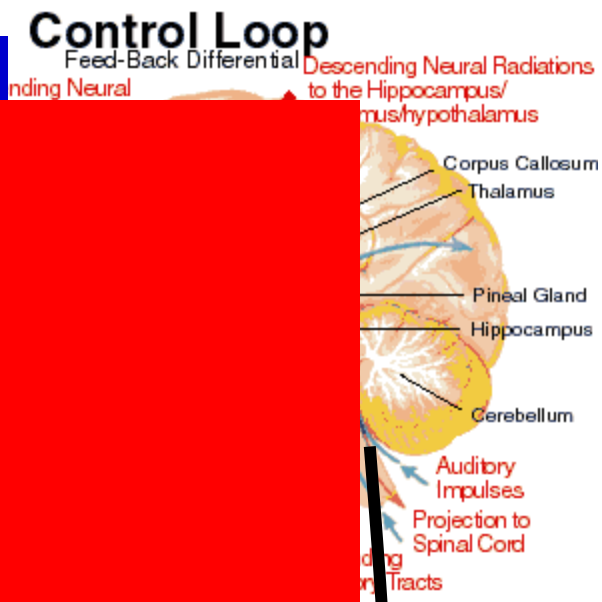
Reflect

Reflex



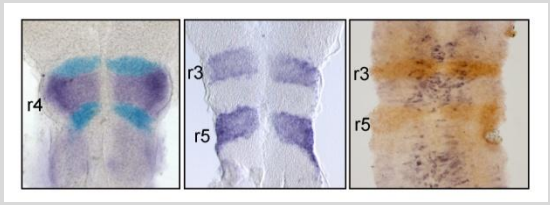


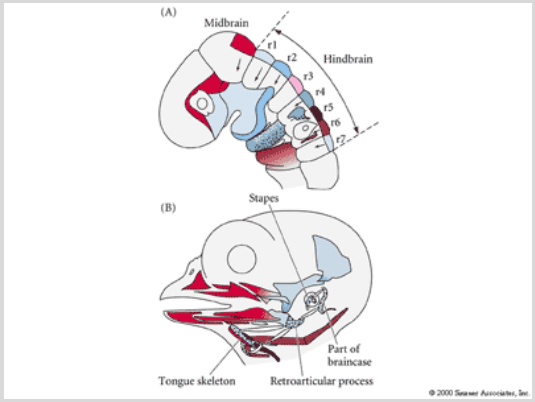
Reflect



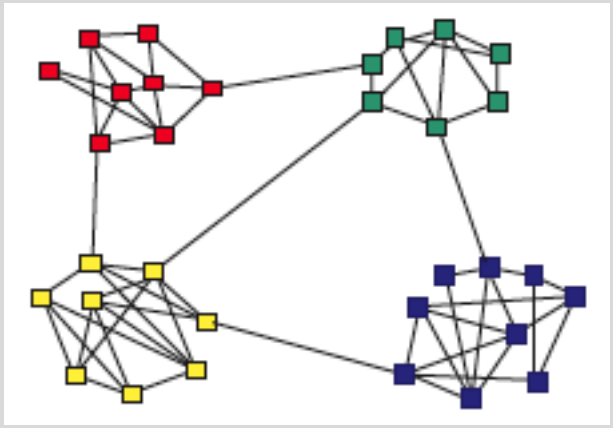
Reflex

There are many meanings of “modularity” in neuroscience: (how) are they related?

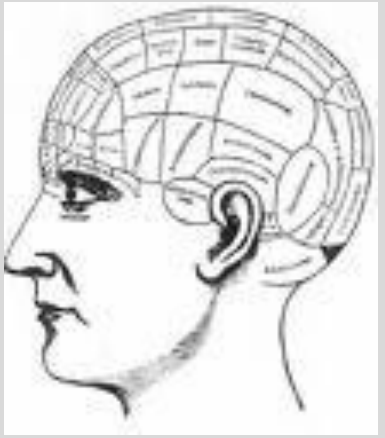




Developmental

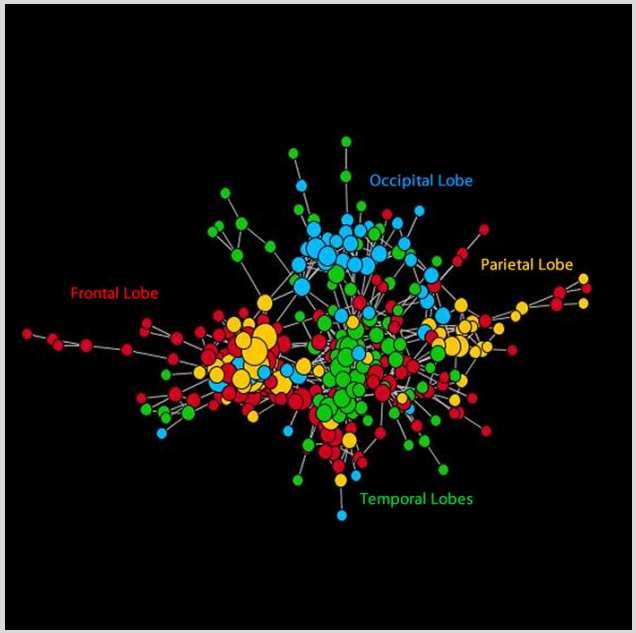


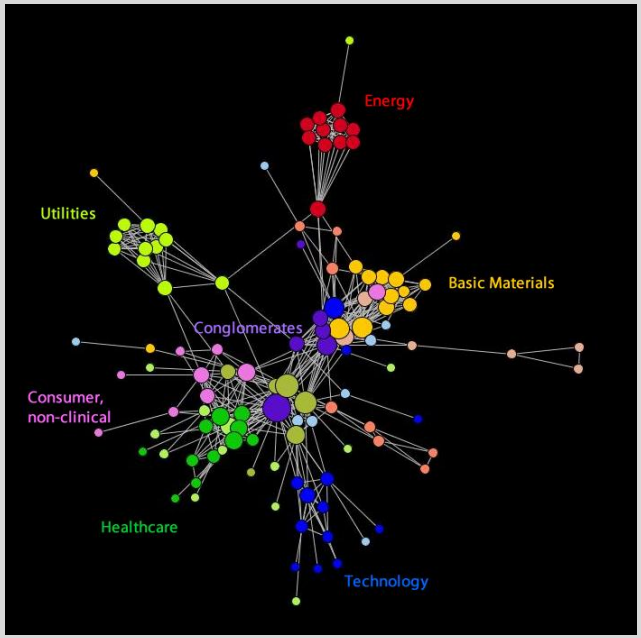
Topological

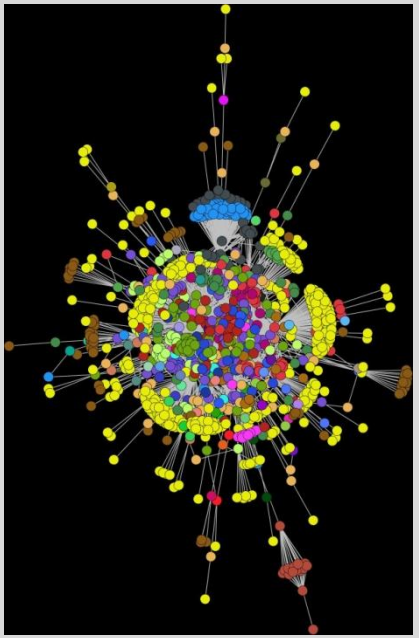


Psychological

What's special and what's not so special about human brains compared to other information networks?



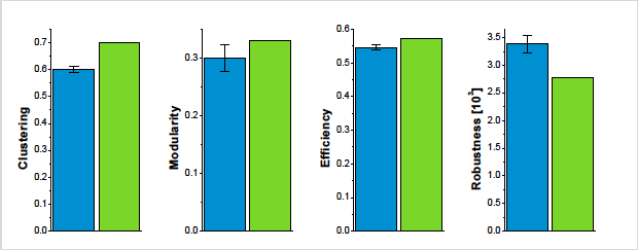




Human Brain Network
Resting state FMRI

Economic Network
New York Stock Exchange

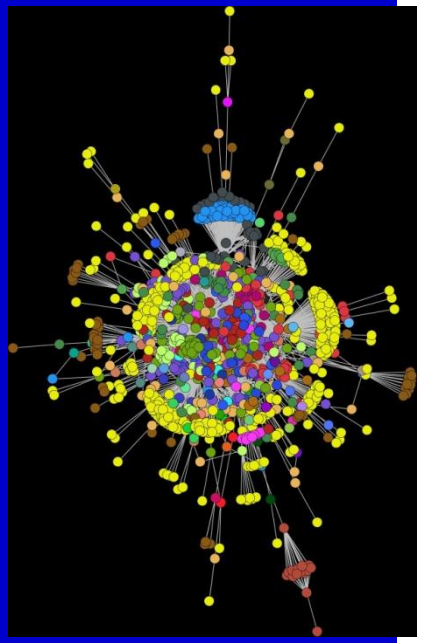
Social Network
Twitter #gadaffi



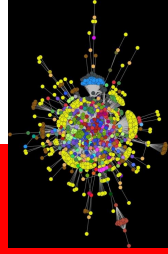
Vertes et al (2011) *Front Sys Neurosci*

What a teenager sees.

“Social network technology”



Hidden Technology

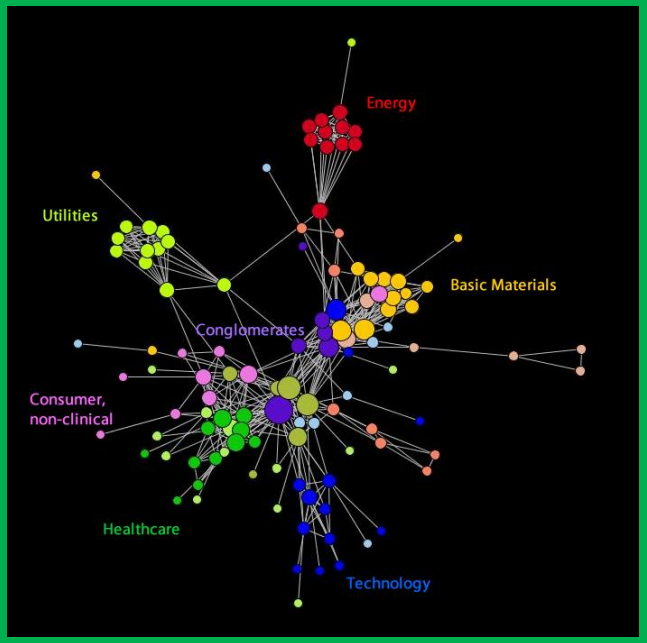


Hidden Technology

What I see

What Wall Street sees.

“Blah blah blah blah blah”



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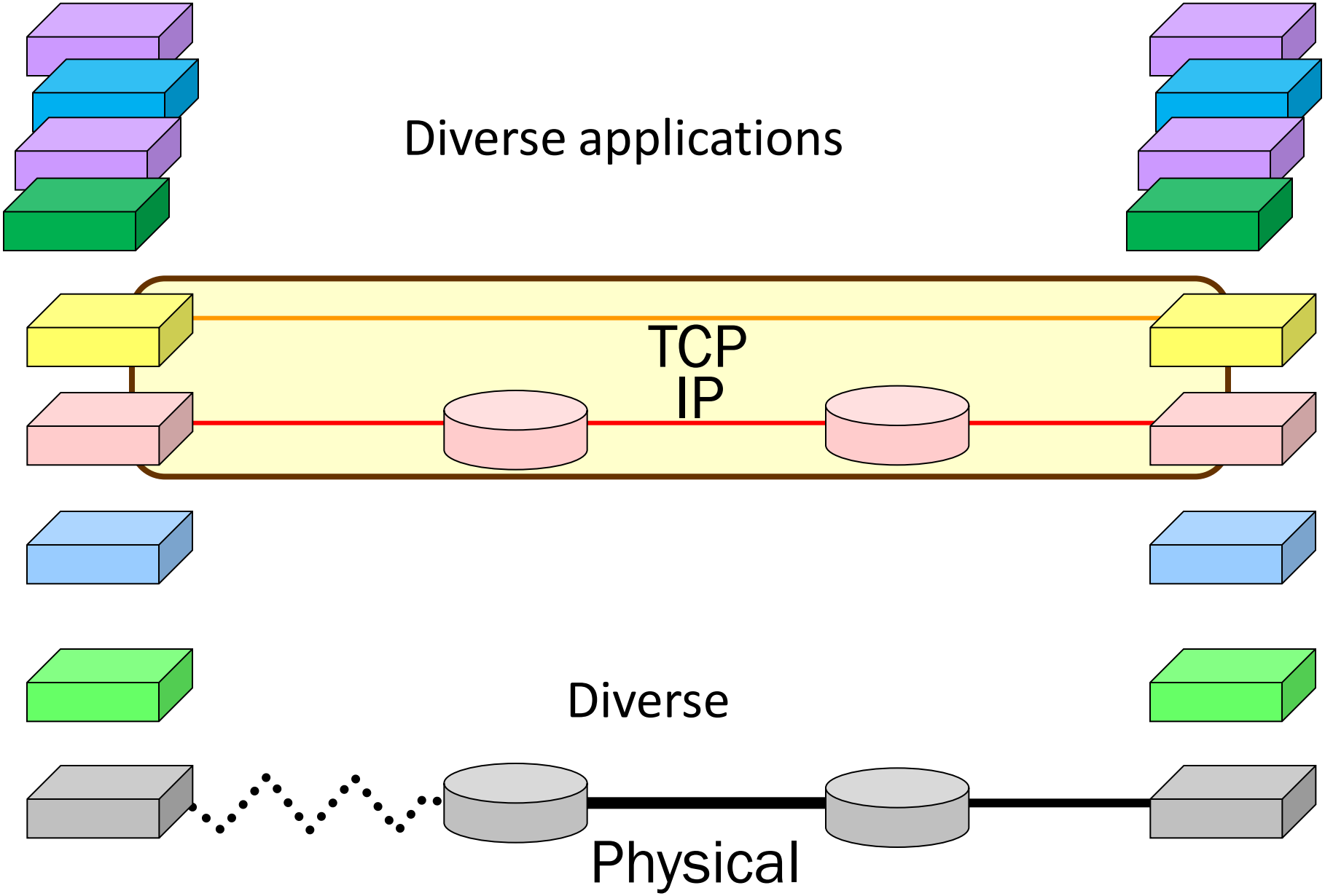
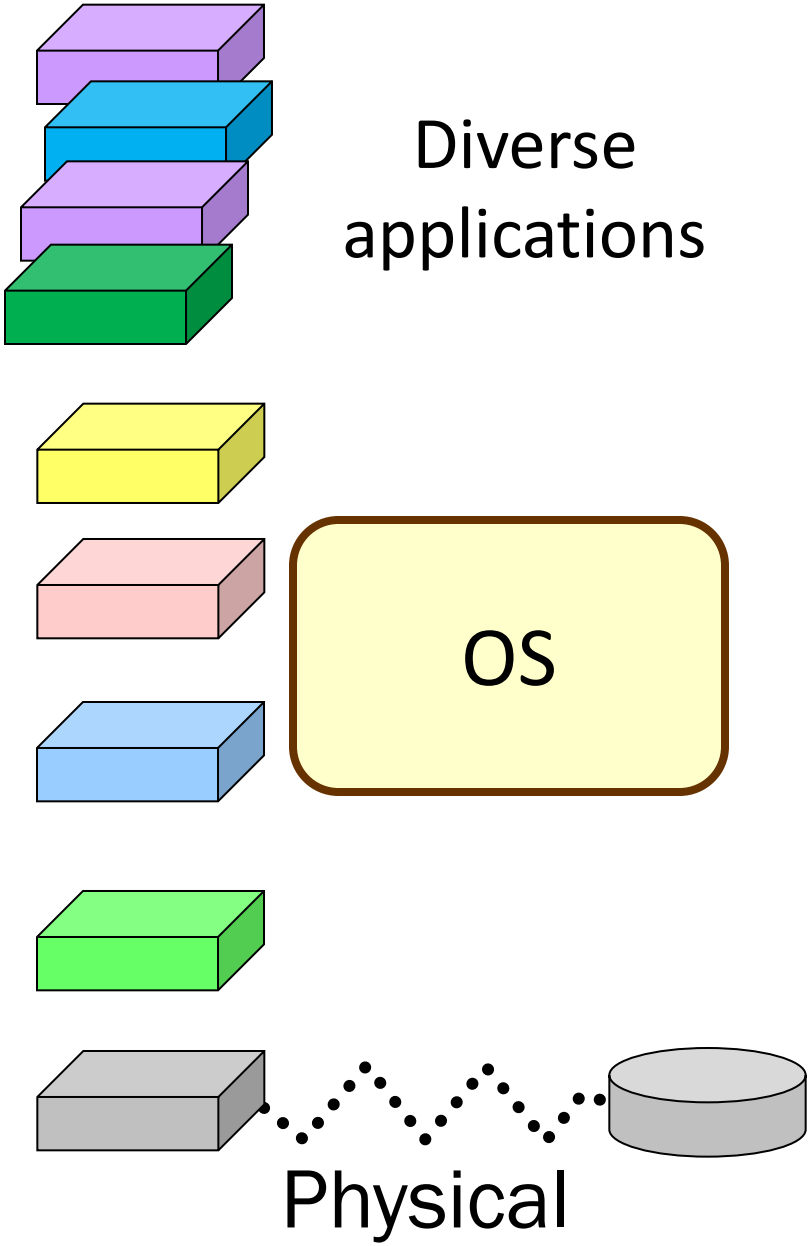
Hidden Technology

Jin’s OS?

Layered architectures



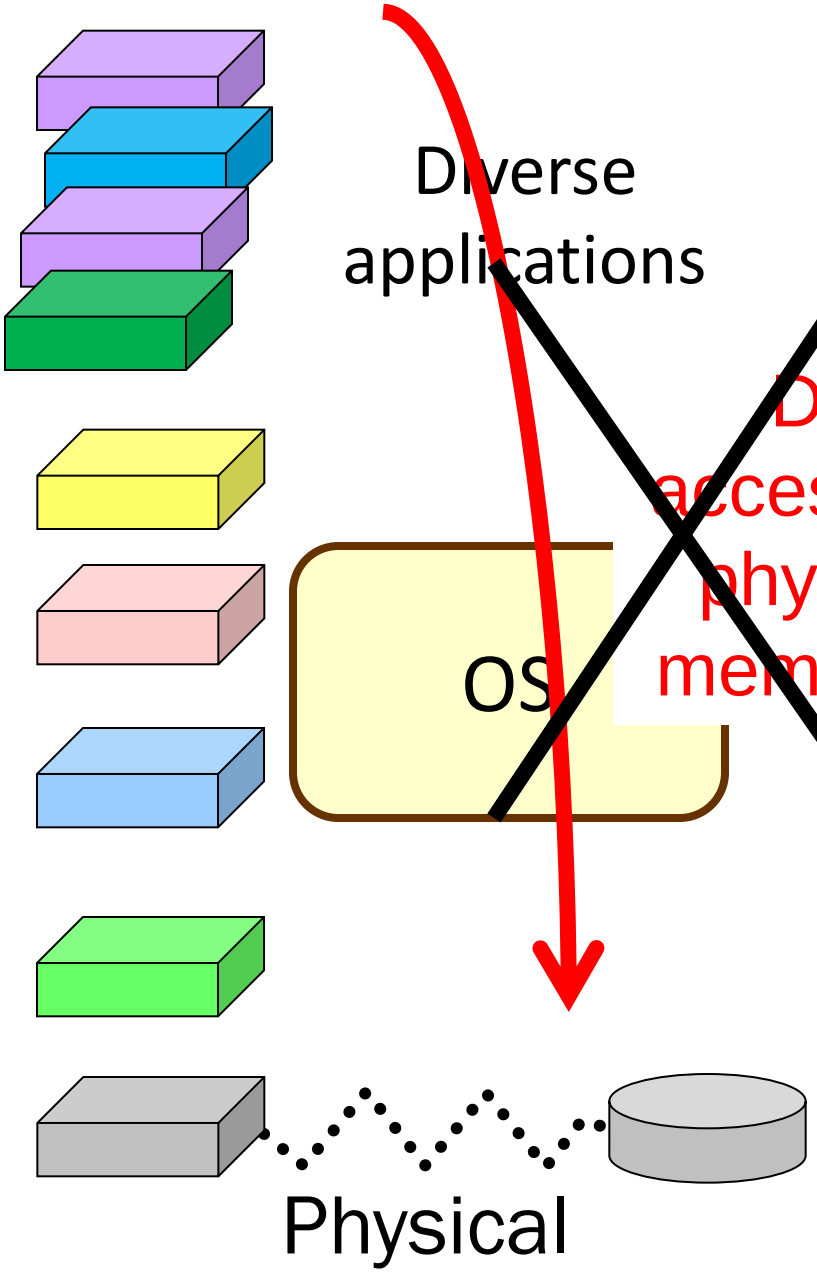
Layered architectures



- OS allocates/shares
  - diverse resources among
  - diverse applications
- "Strict layering" crucial, e.g. clearly separate
  - Application name space
  - Logical (virtual) name/address space
  - Physical (name/) address space

- Name resolution w/in appls
- Name/addr transl X layers

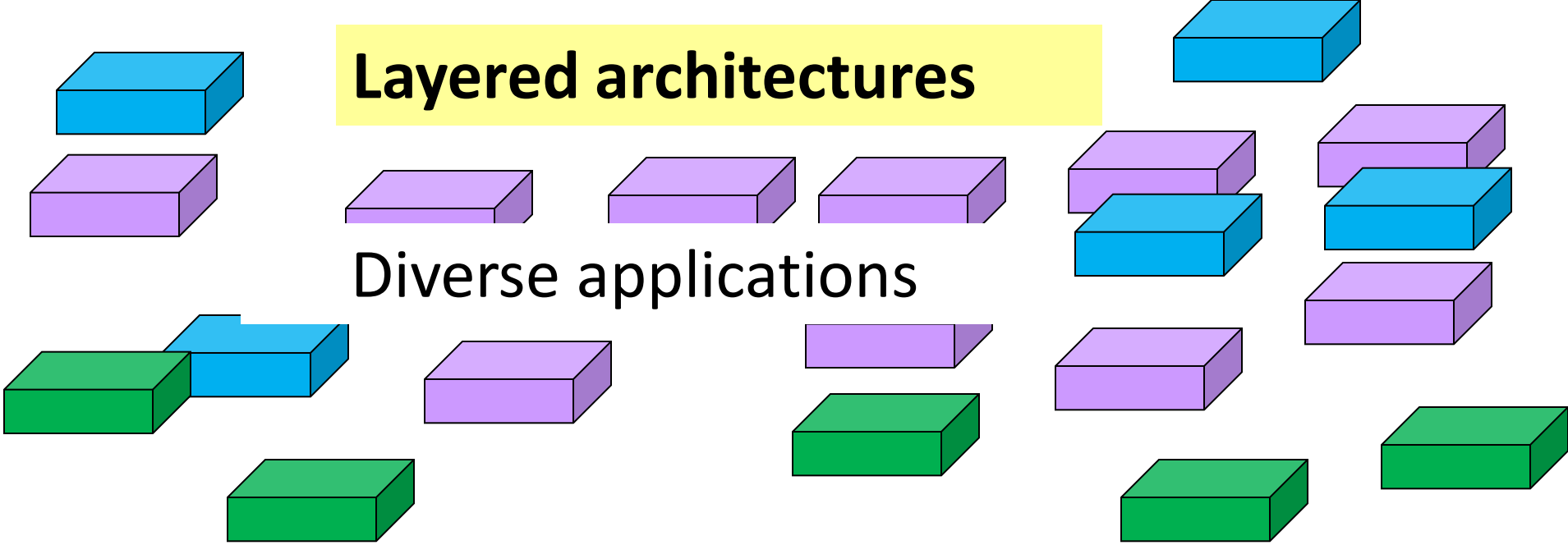
Layered architectures



In programming:
No global variables

In operating systems:
Don't cross layers (rings)

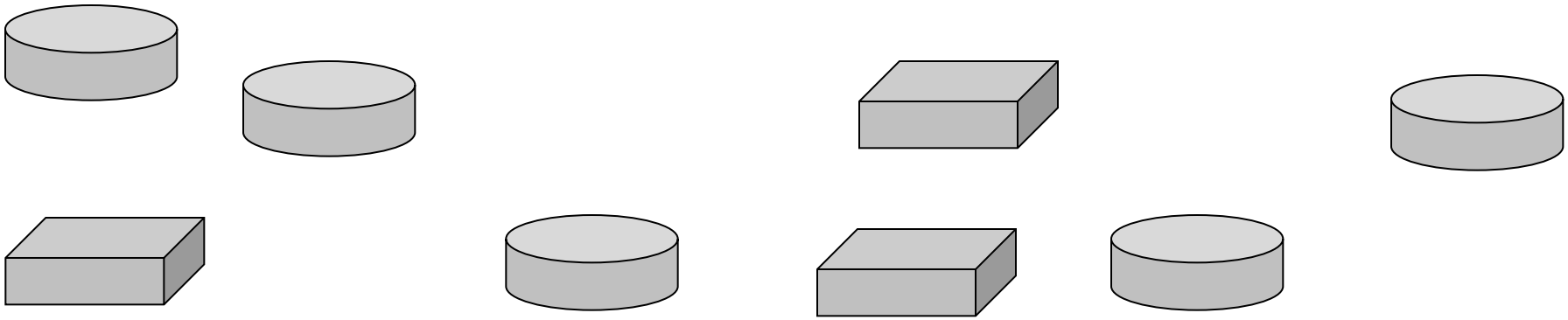
Layered architectures



Diverse applications

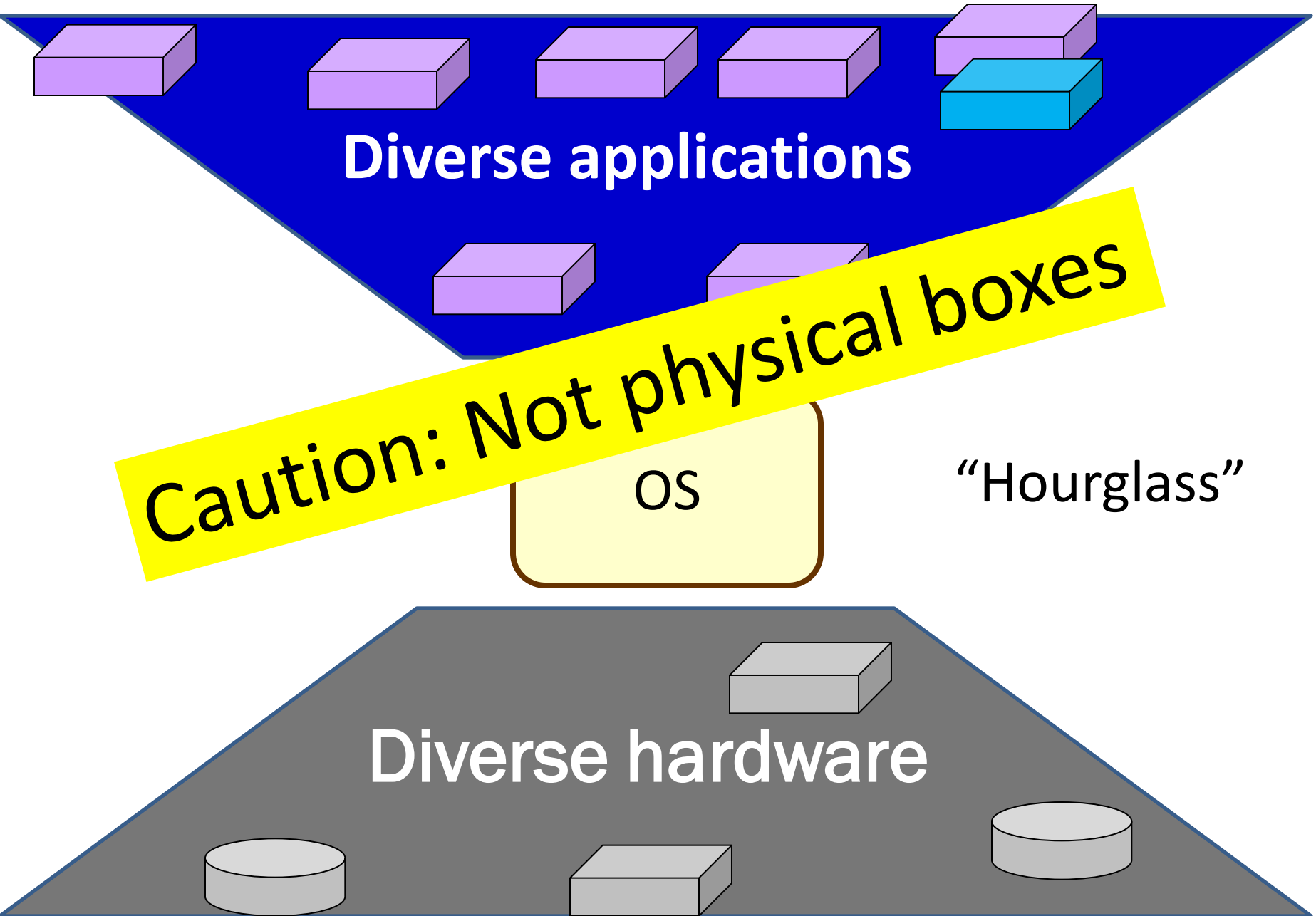
OS

Little diversity

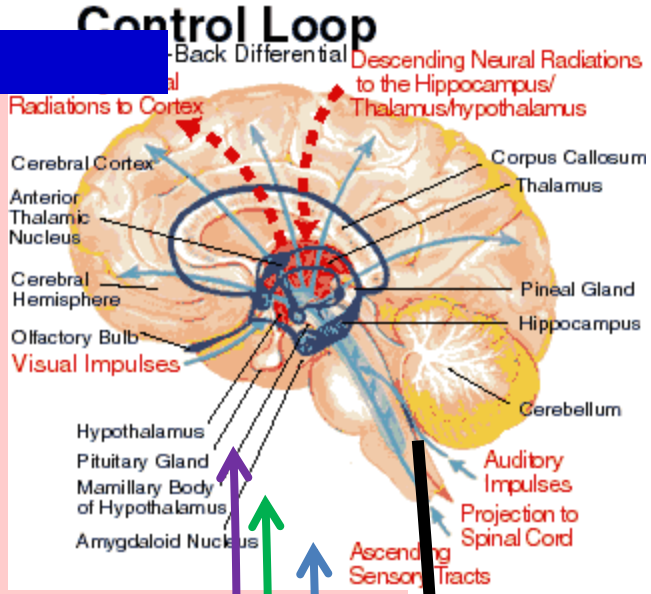


Diverse hardware

Layered architectures



Reflect



"OS"

Reflex

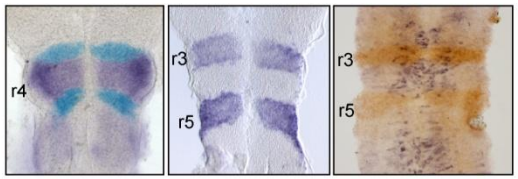
sense

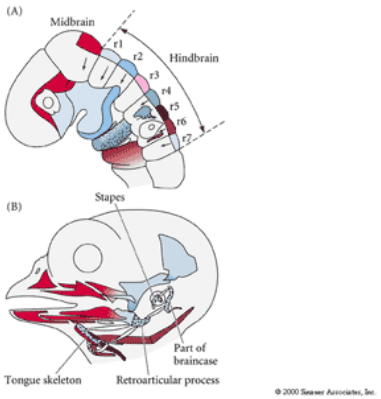
move

Spine

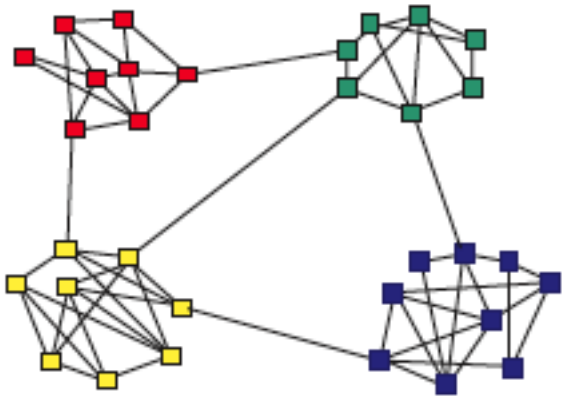
Jin’s OS?

There are many meanings of “modularity” in neuroscience: (how) are they related?





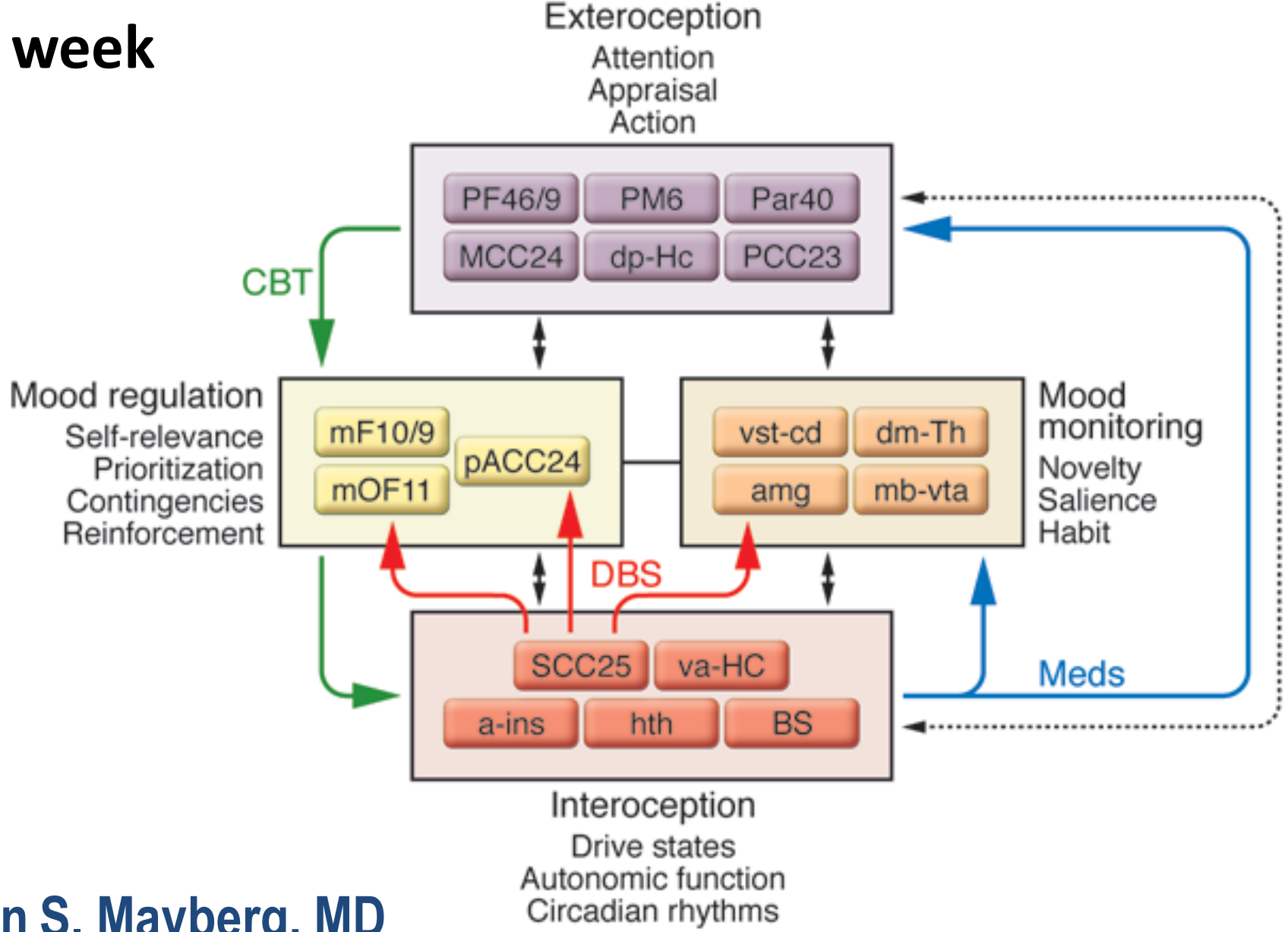
Developmental



Topological

Psychological

Last week



Helen S. Mayberg, MD

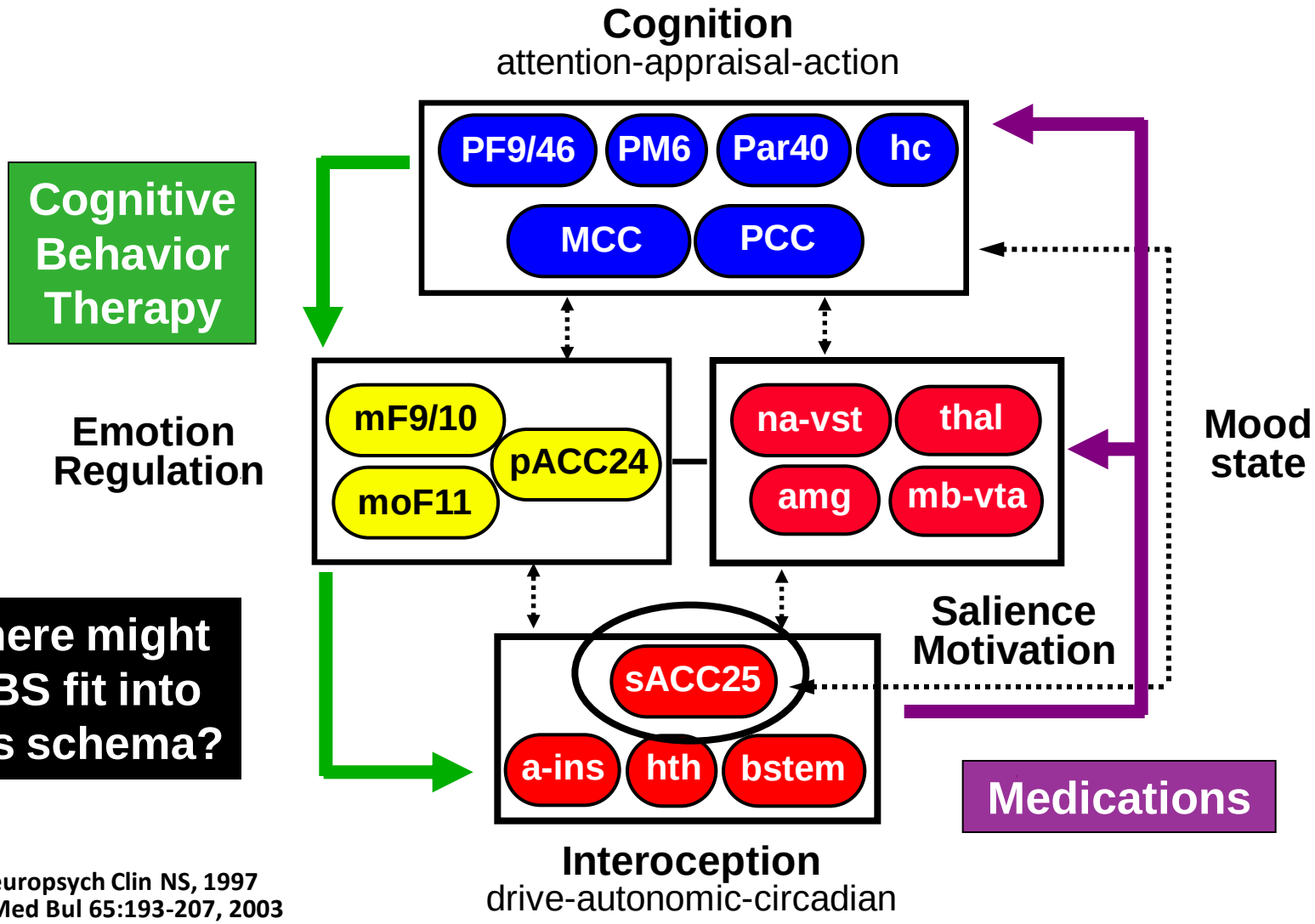
Professor, Psychiatry and Neurology

Dorothy C. Fuqua Chair in Psychiatric Neuroimaging and Therapeutics

Emory University School of Medicine

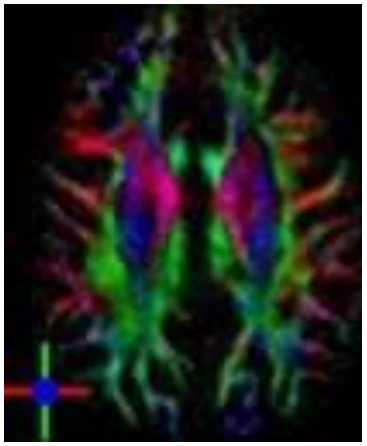
Putative "Depression" Network ~ 2001

defined using functional imaging

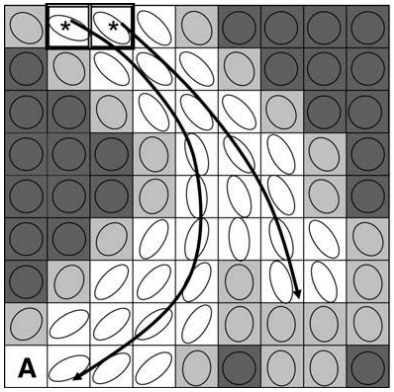


Mayberg, J Neuropsych Clin NS, 1997
Mayberg, Br Med Bul 65:193-207, 2003
Mayberg, J Clin Invest 119:717, 2009

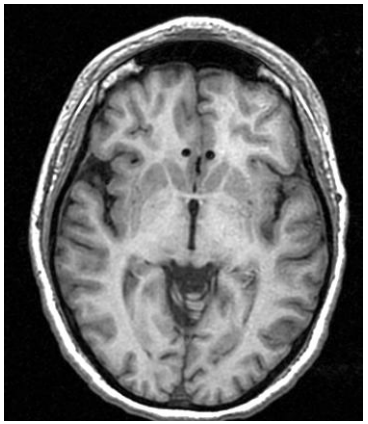
Rethinking Critical Pathways
Mapping Fibers of Passage thru SCC25



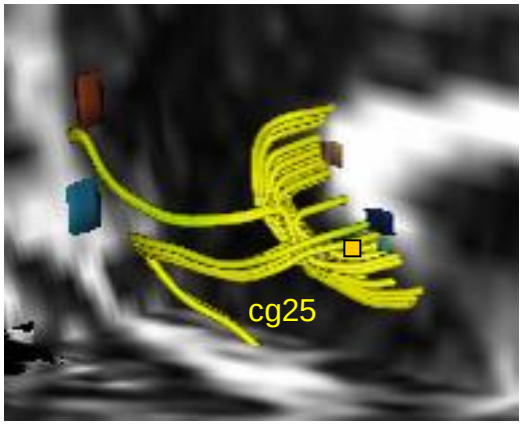
Diffusion Tensor Imaging



Fiber Assignment by Continuous Tracking along adjacent pixels



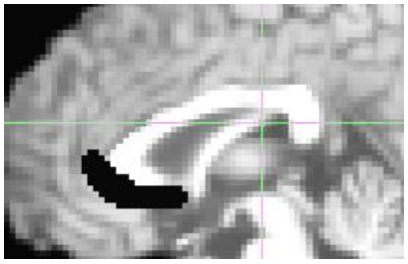
Cg25WM Target

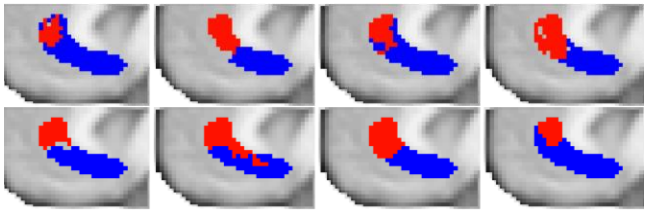


Tracts thru Seed

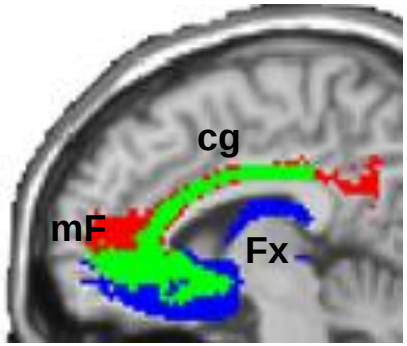
Probablistic Tractography

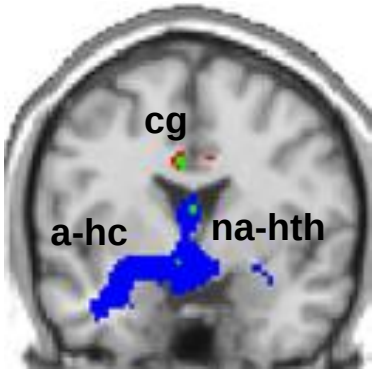
Cingulate ROI





DTI: Blind ACC Parcellation →
SVD 2 clusters: sACC ≠ Pacc (n=18)





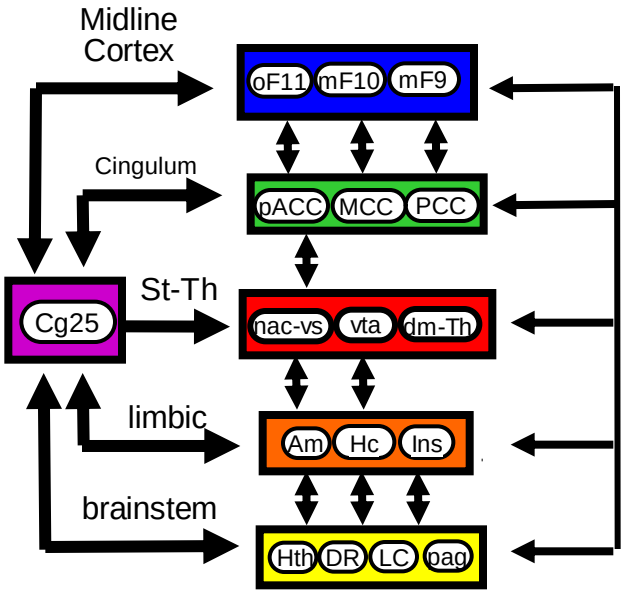
Overlap
Unique inferior ROI
Unique superior ROI

Johansen-Berg et al
Cerebral Cortex 2008

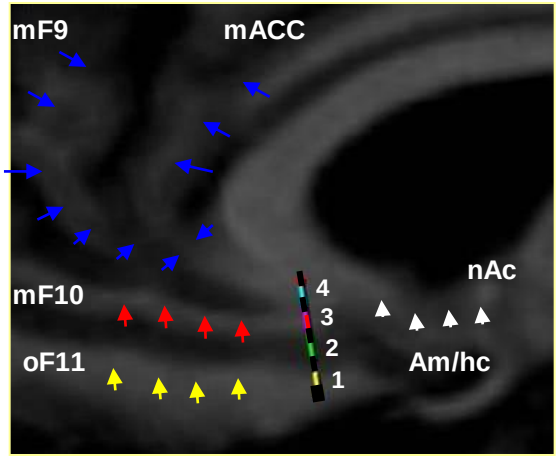
Rethinking Critical Pathways

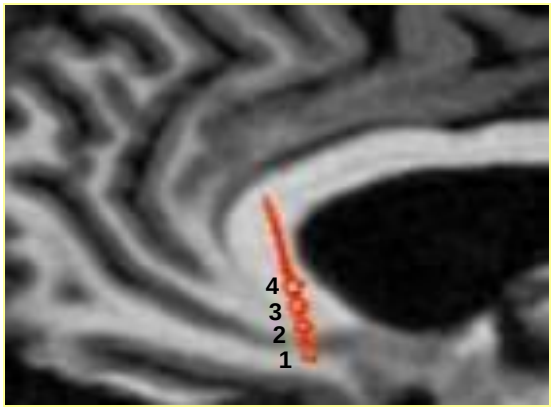
Mapping Fibers of Passage thru SCC25

Model



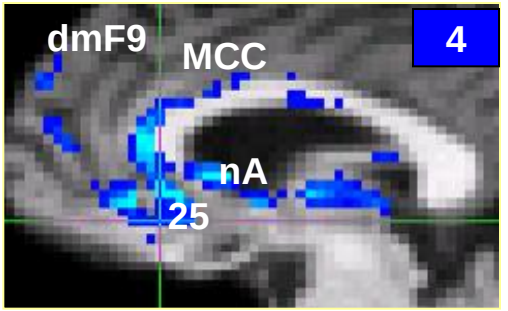
Define tracts affected by stimulation

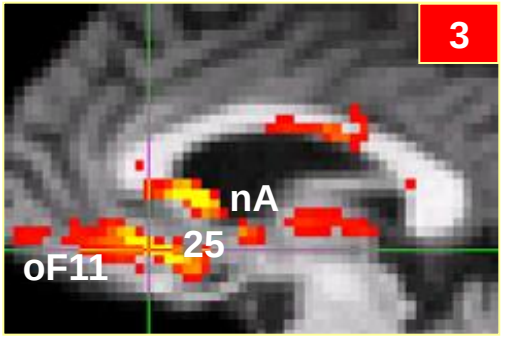


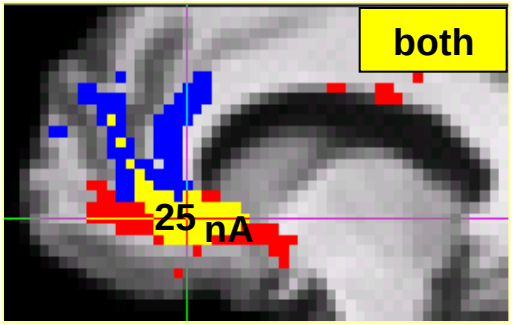


Post-op CT/MRI merge

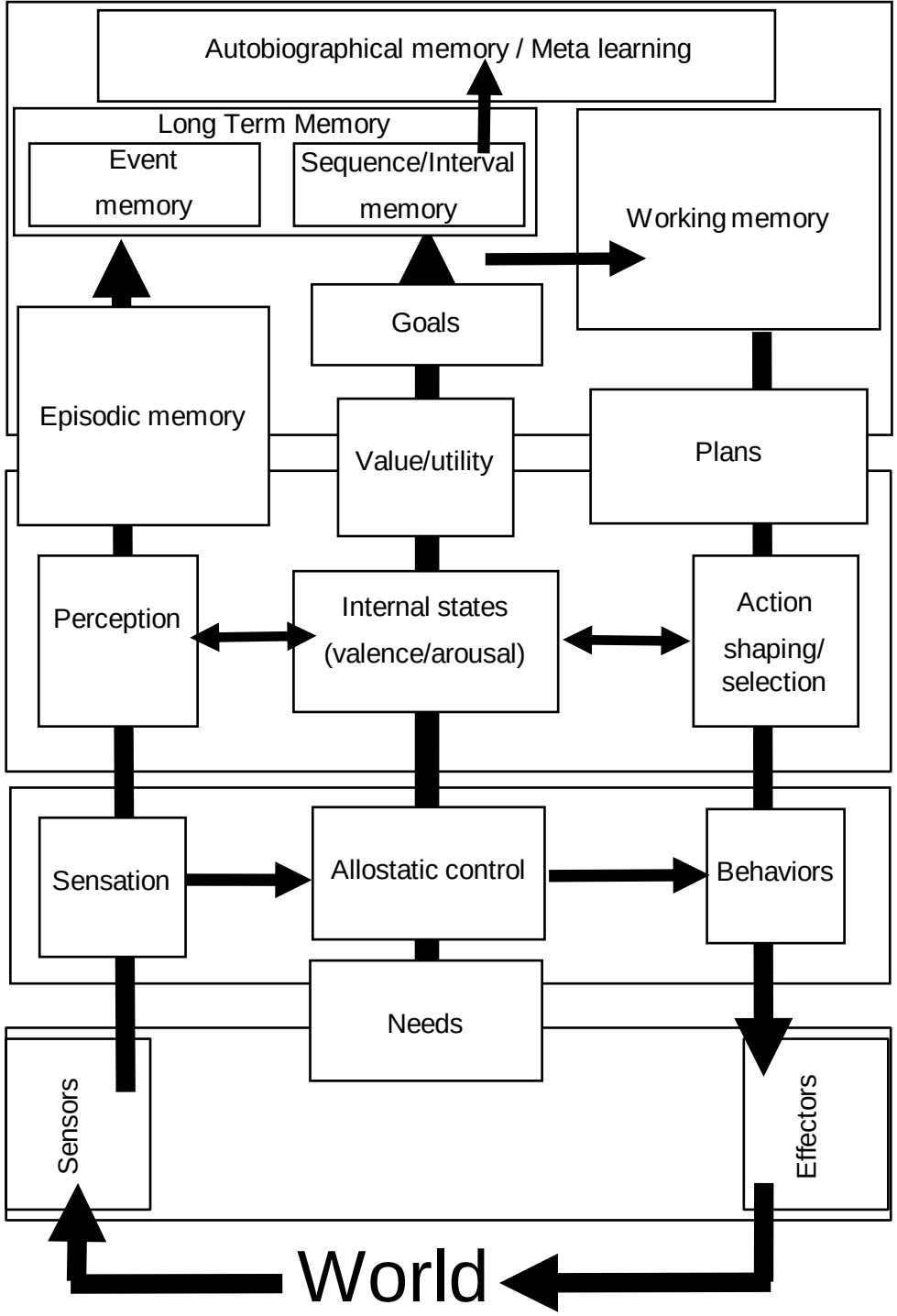
Differences between Adjacent contacts







The Distributed Adaptive Control Architecture



Duff et al (2011) Br.Res.Bull.

Duff et al (2010) Neurocomputing

Sanches et al (2010) Adv Compl Sys

Mathews et al (2009;2010) IROS09;IC

Eng et al (2003;2005) ICRA; IEEE Tr S

Verschure et al (2003) Nature (425) 6

Verschure & Althaus (2003) Cogn. Sc

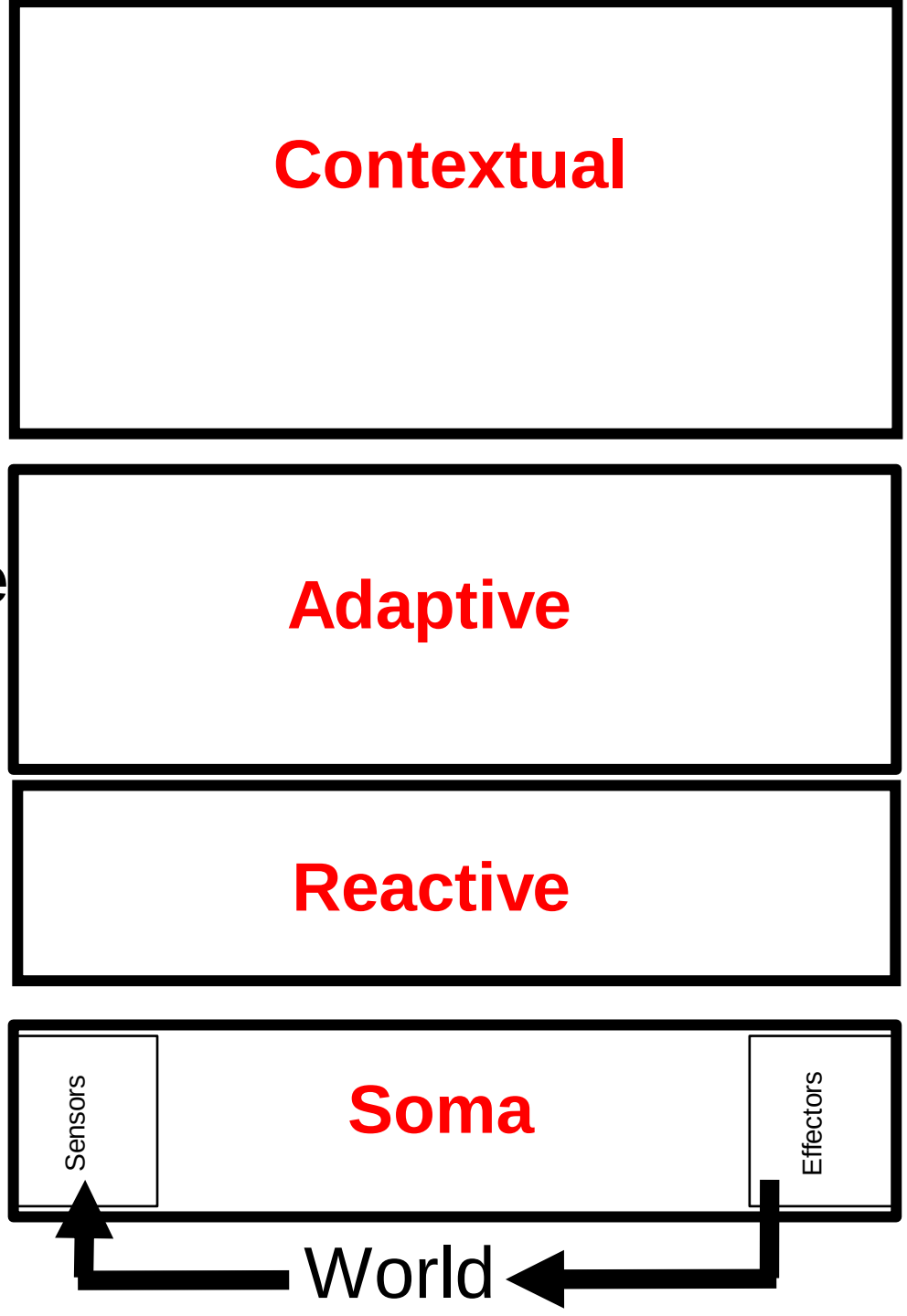
Verschure & Voegtlin (1998) Neural N

Verschure et al (1992) Rob. Aut. Sys.

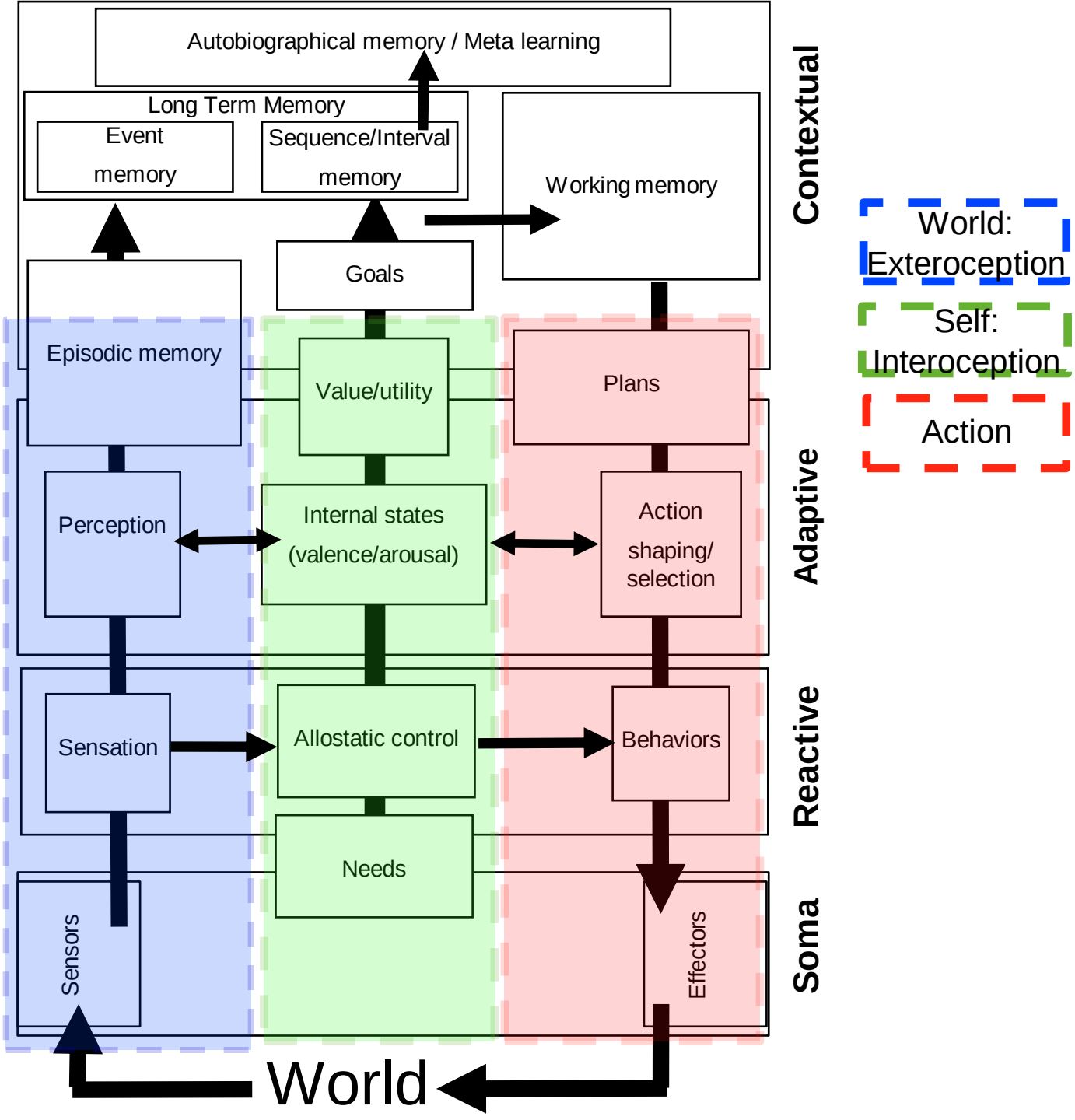
Verschure & Coolen (1991) Network

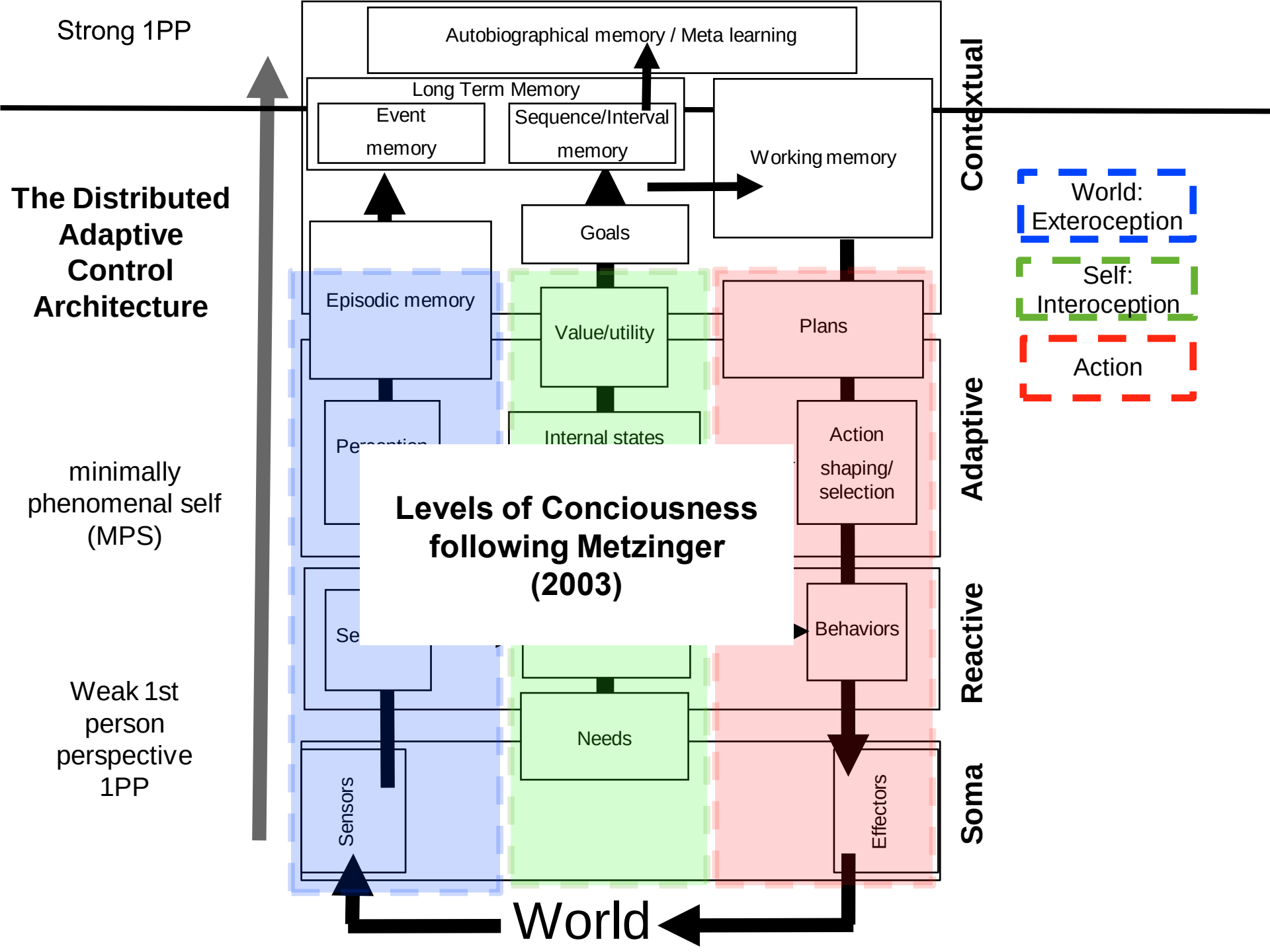
Paul Verschure

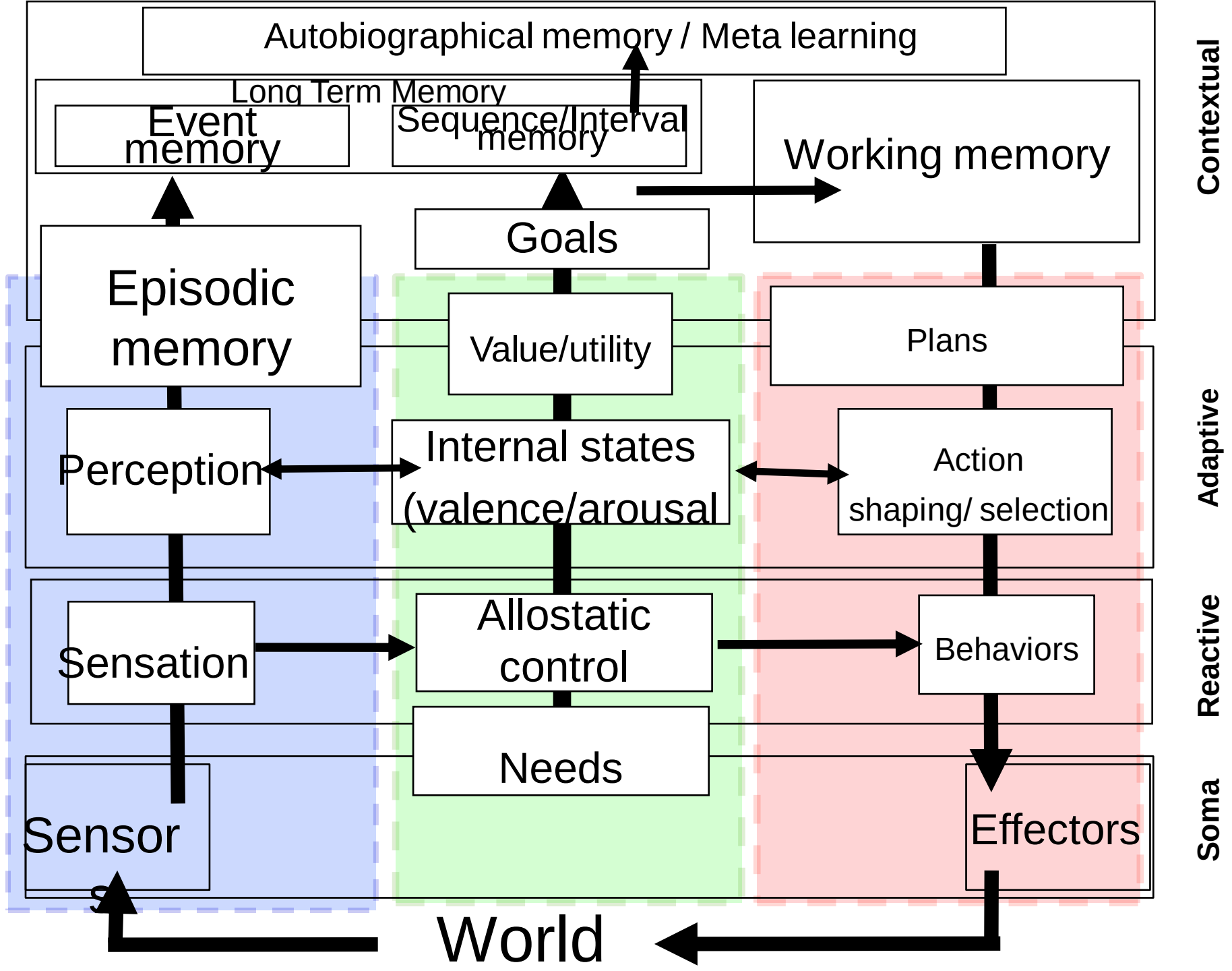
Layered
Distributed
Adaptive
Control
Architecture



The Distributed Adaptive Control Architecture




Strong 1PP
The Distributed Adaptive Control Architecture
minimally phenomenal self (MPS)
Weak 1st person perspective 1PP
Autobiographical memory / Meta learning
Long Term Memory
Event memory
Sequence/Interval memory
Working memory
Goals
Episodic memory
Value/utility
Plans
Internal states
Action shaping/ selection
Behaviors
Needs
Sensors
Effectors
World
Contextual
Adaptive
Reactive
Soma
World: Exteroception
Self: Interoception
Action
Levels of Conciousness following Metzinger (2003)


Autobiographical memory / Meta learning
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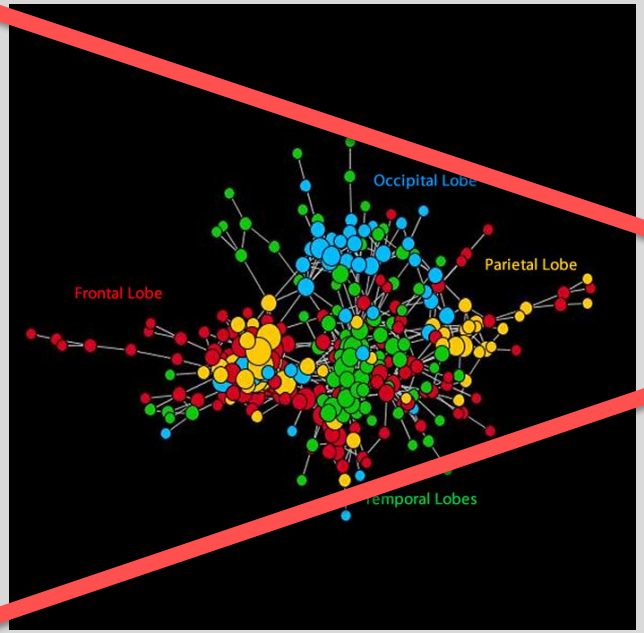
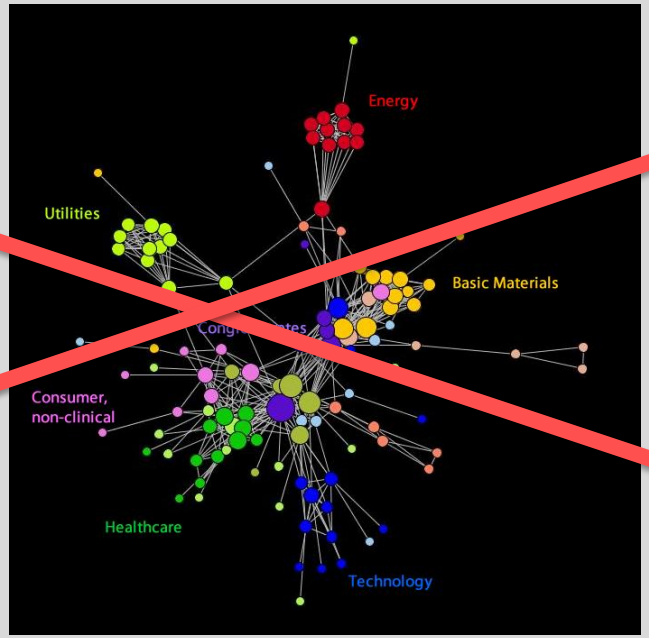
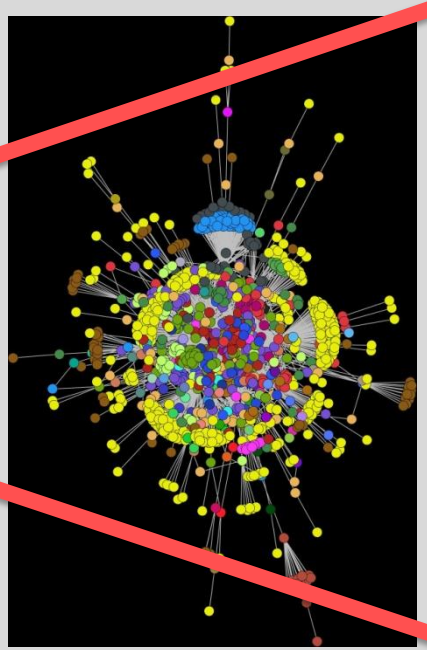
Working memory
Goals
Episodic memory
Value/utility
Plans
Perception
Internal states (valence/arousal
Action shaping/ selection
Sensation
Allostatic control
Behaviors
Needs
Sensor s
Effectors
World
Contextual
Adaptive
Reactive
Soma

What's special and what's not so special about human brains compared to other information networks?



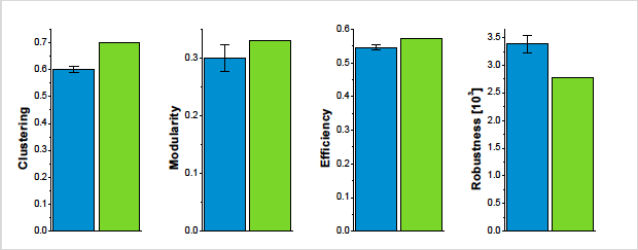




Human Brain Network
Resting state FMRI

Economic Network
New York Stock Exchange

Social Network
Twitter #gadaffi



Vertes et al (2011) *Front Sys Neurosci*

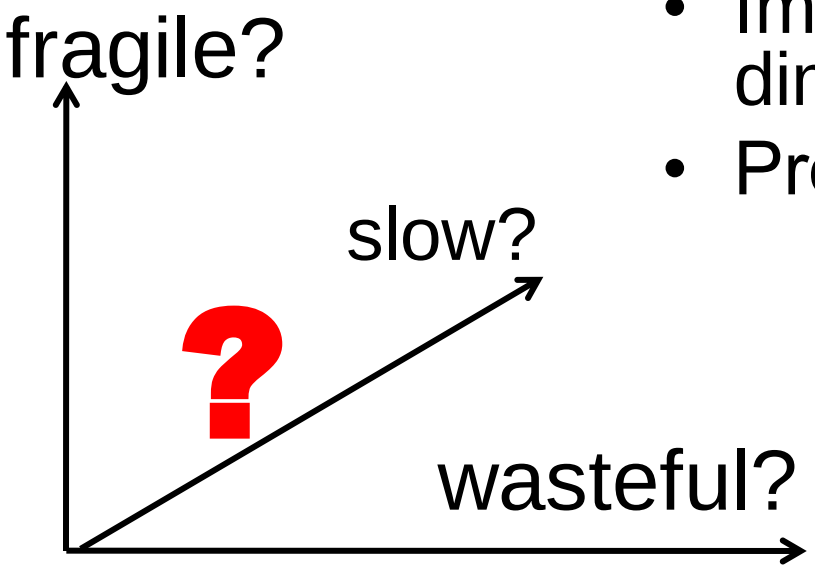
Control

Bode

Comms

Shannon

- Each theory ≈ one dimension
- Important tradeoffs ***across*** dimensions
- Progress is encouraging but…



Carnot

Turing

Boltzmann

Godel

Heisenberg

Compute

Physics

Einstein

Why do we build or evolve complex networks in the first place?

Demand!

Supply?

Mismatch between application demand and resource supply

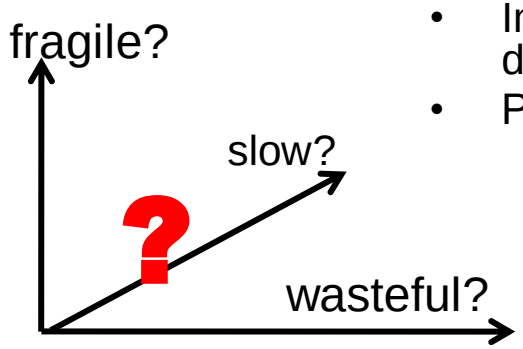
Control

Bode

Comms

Shannon

- Each theory ≈ one dimension
- Important tradeoffs ***across*** dimensions
- Progress is encouraging but…



Supply?

Carnot

Boltzmann

Heisenberg

Einstein

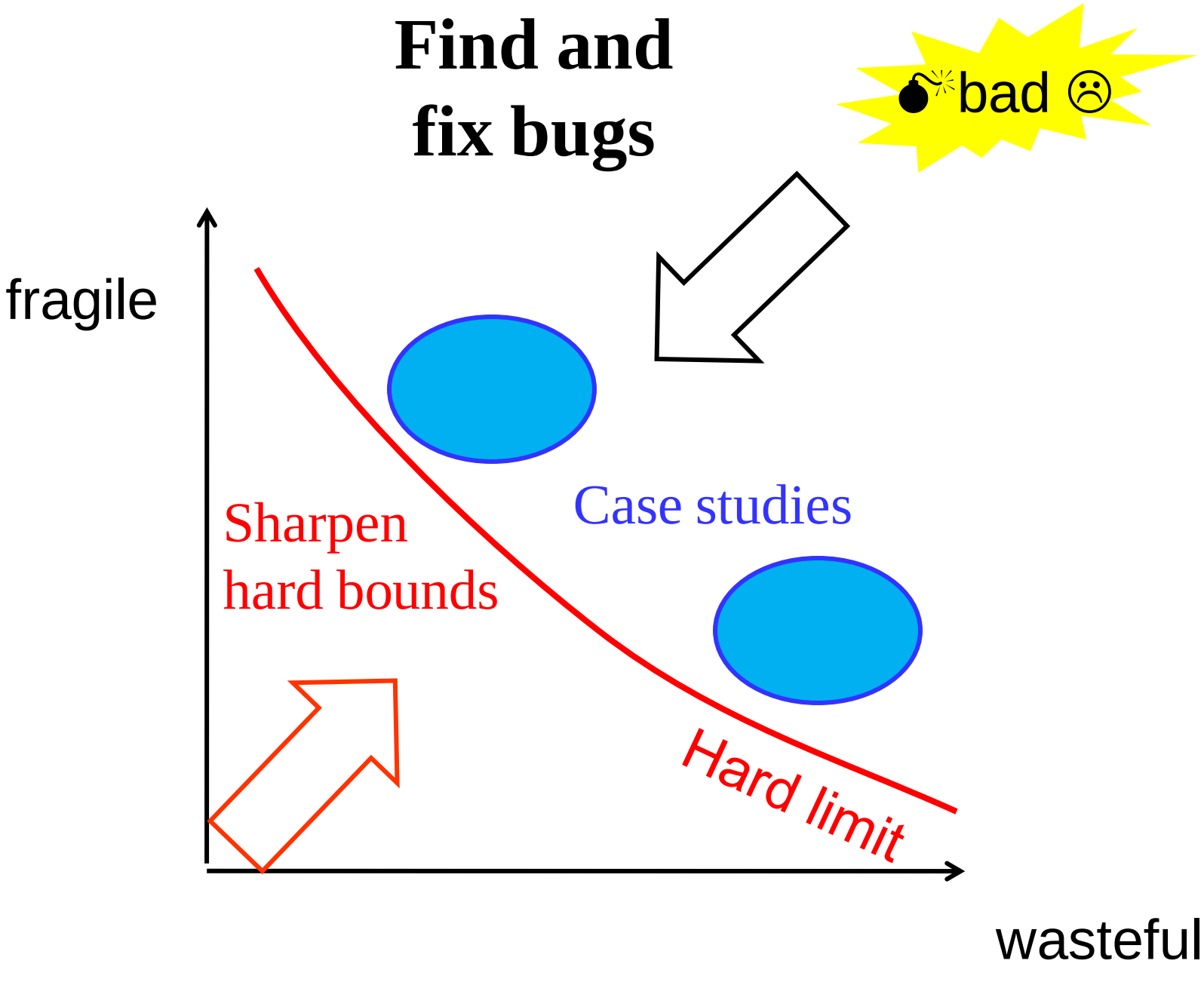
Physics

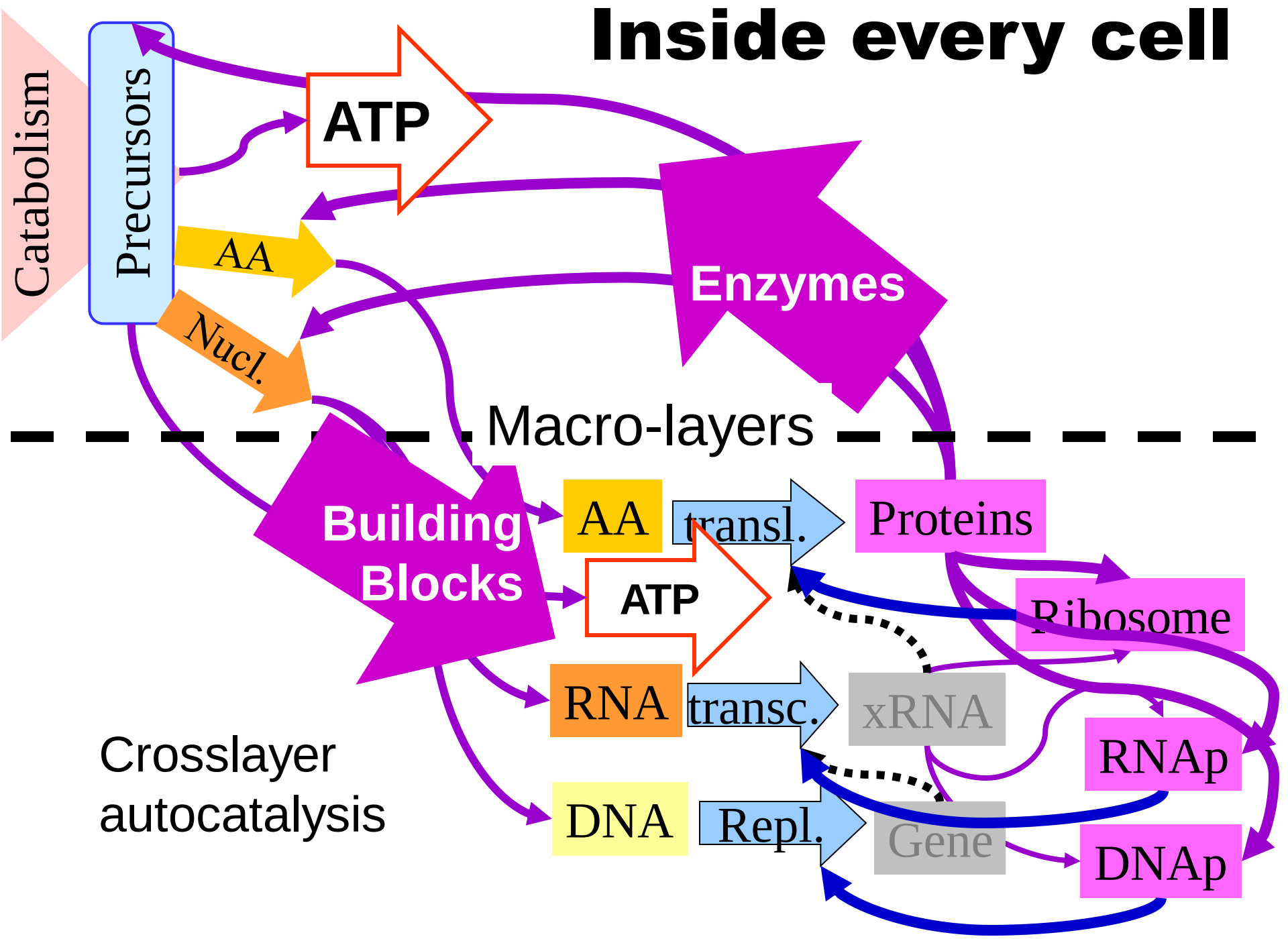
Turing

Godel

Compute

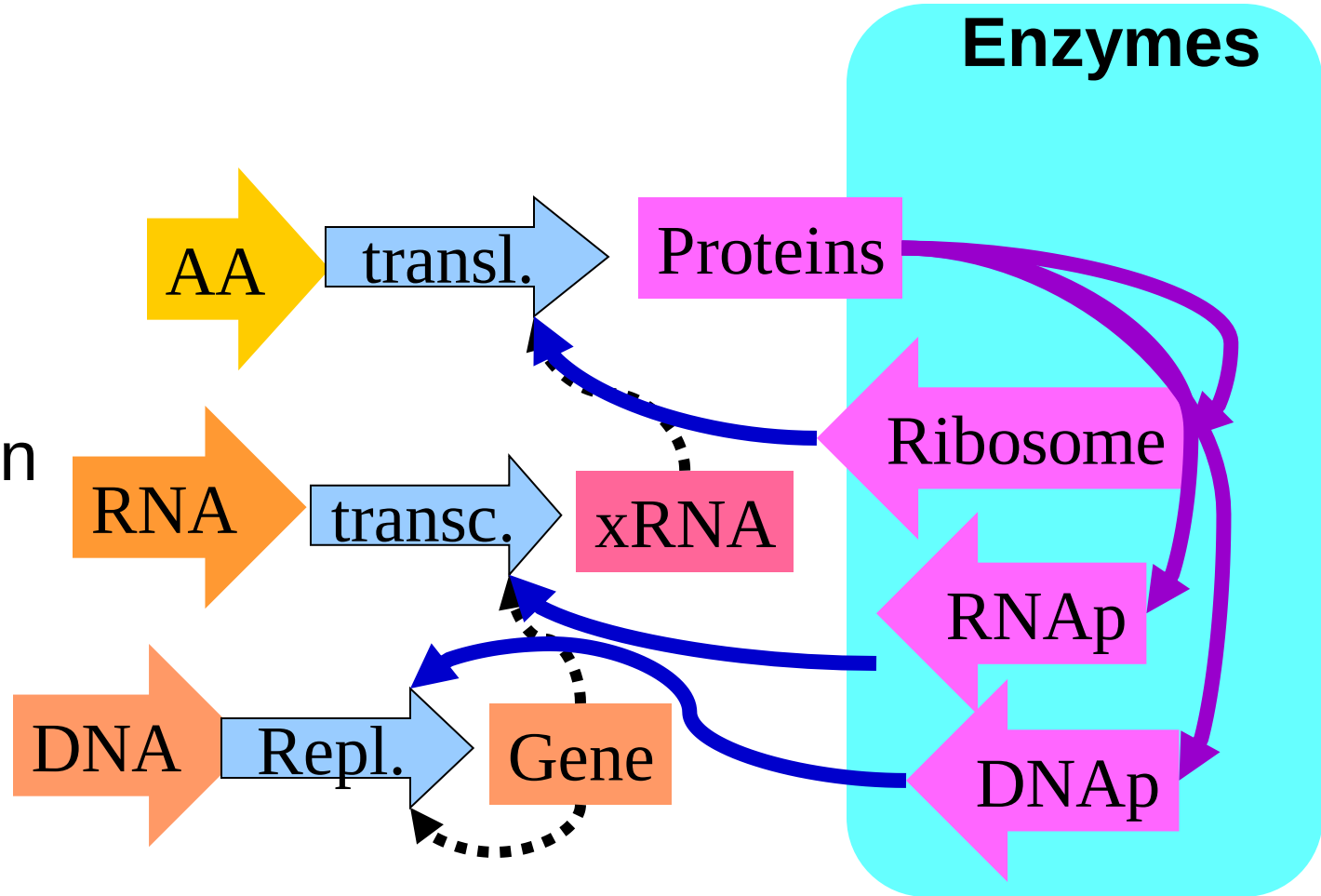
Find and fix bugs



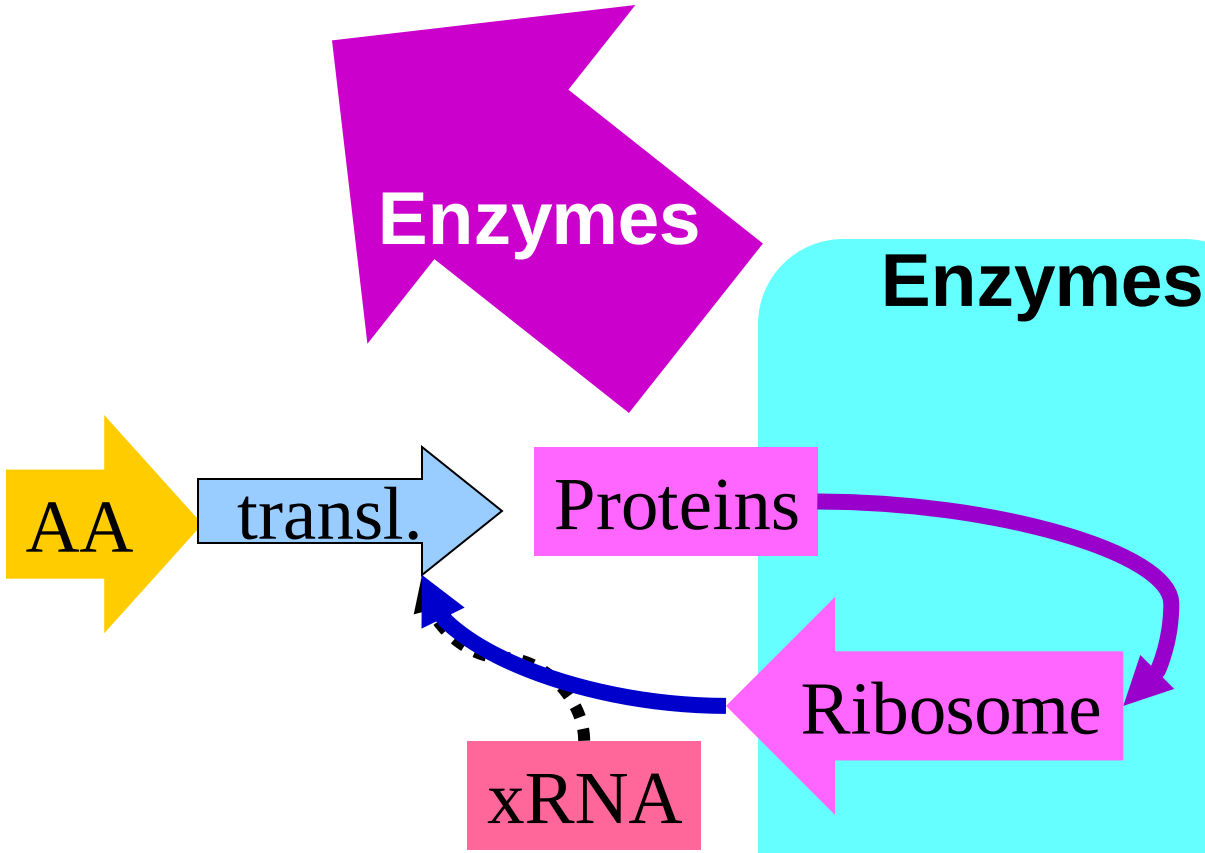

Inside every cell
Catabolism
Precursors
ATP
AA
Nucl.
Enzymes
Macro-layers
Building Blocks
AA
transl.
Proteins
ATP
Ribosome
RNA
transc.
xRNA
RNAp
DNA
Repl.
Gene
DNAp
Crosslayer autocatalysis

Lower layer autocatalysis
Macromolecules making …

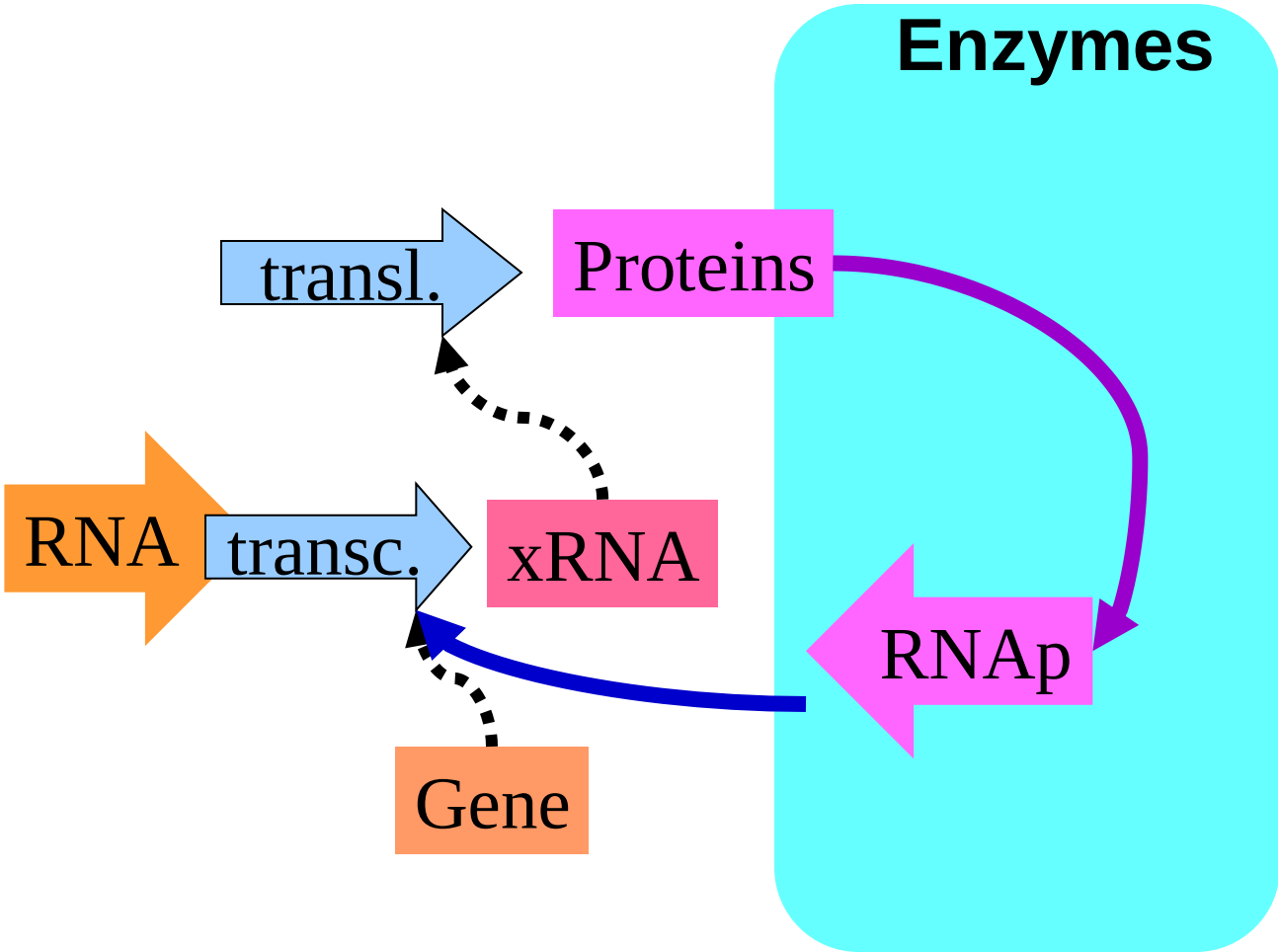
Three lower layers? Yes:
- Translation
- Transcription
- Replication



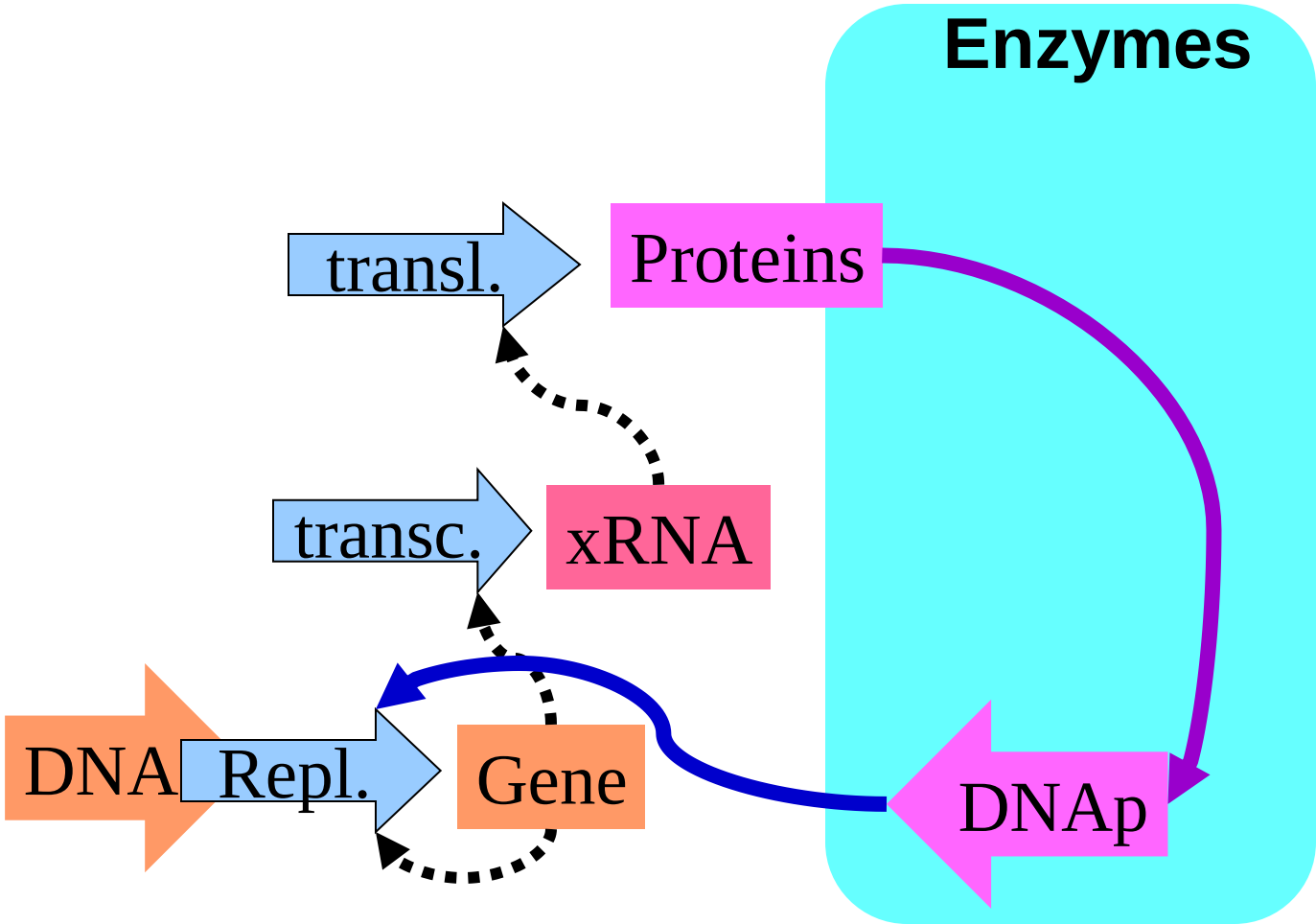
- **Translation**
- Transcription
- Replication

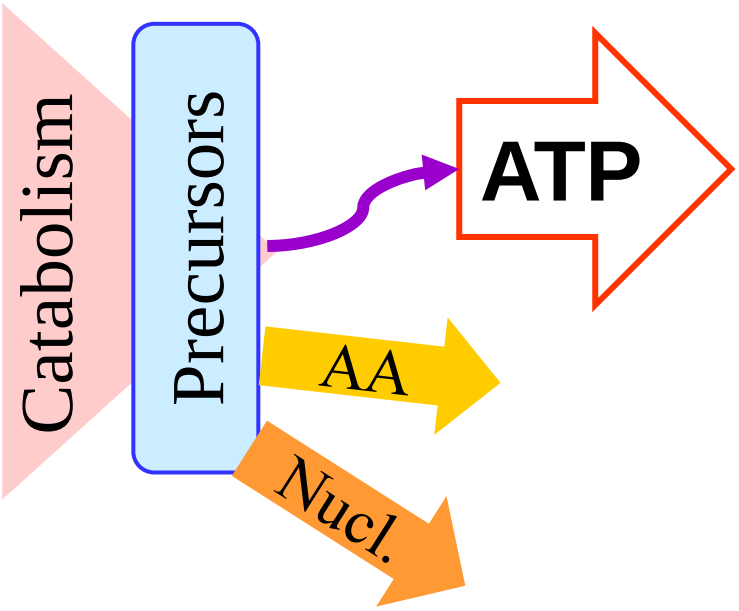


- Translation
- **Transcription**
- Replication

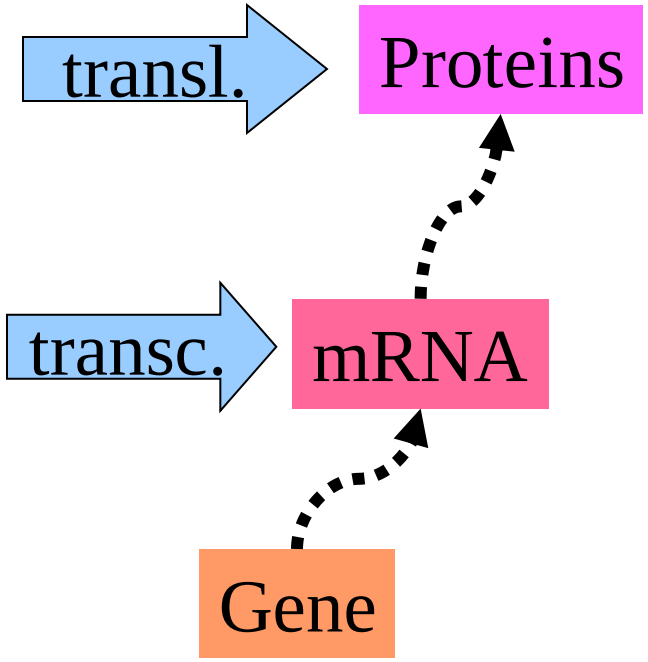


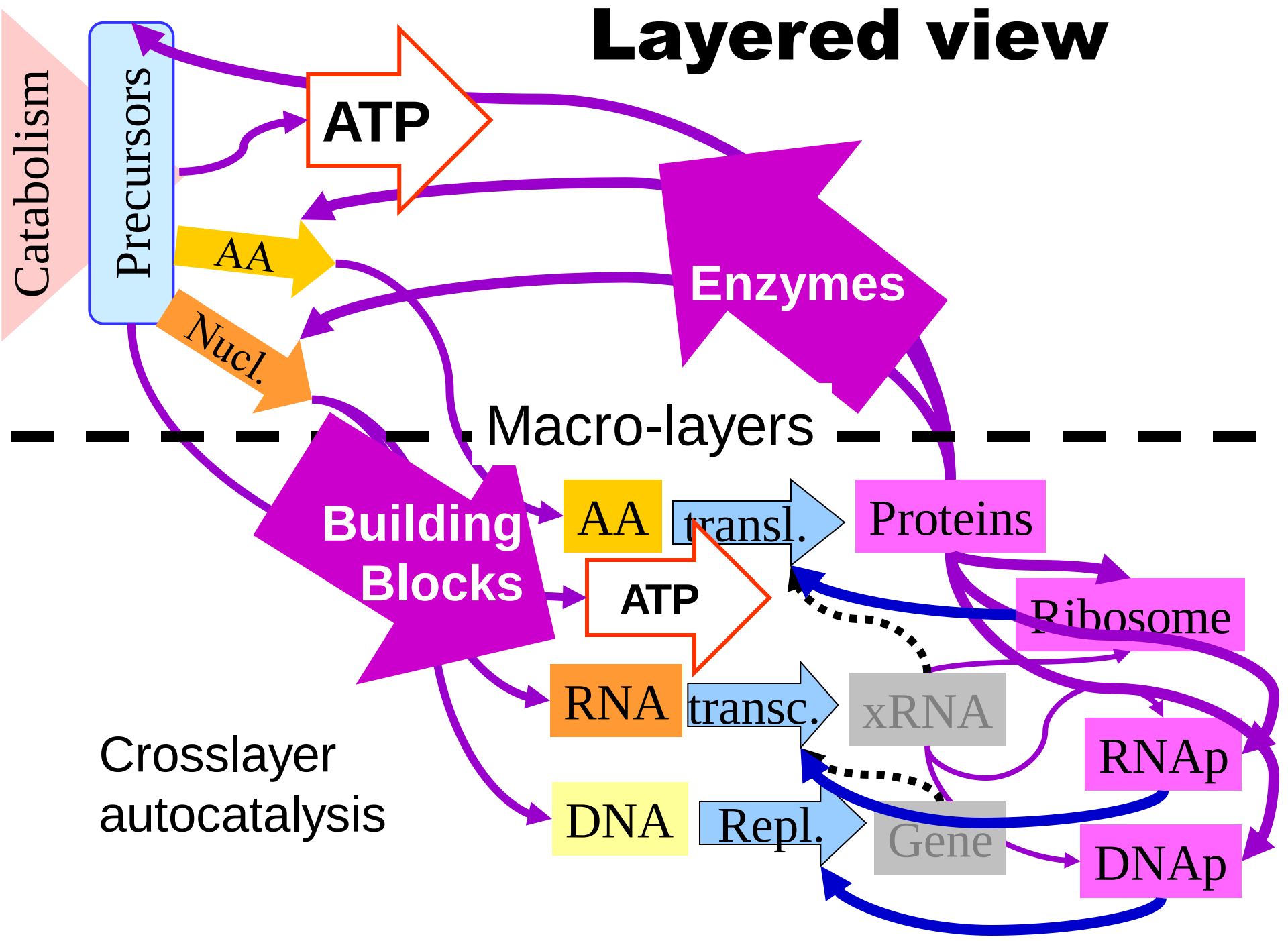
- Translation
- Transcription
- **Replication**





Pathway views




Layered view
Catabolism
Precursors
ATP
AA
Nucl.
Enzymes
Macro-layers
Building Blocks
AA
transl.
Proteins
ATP
Ribosome
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xRNA
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Repl.
Gene
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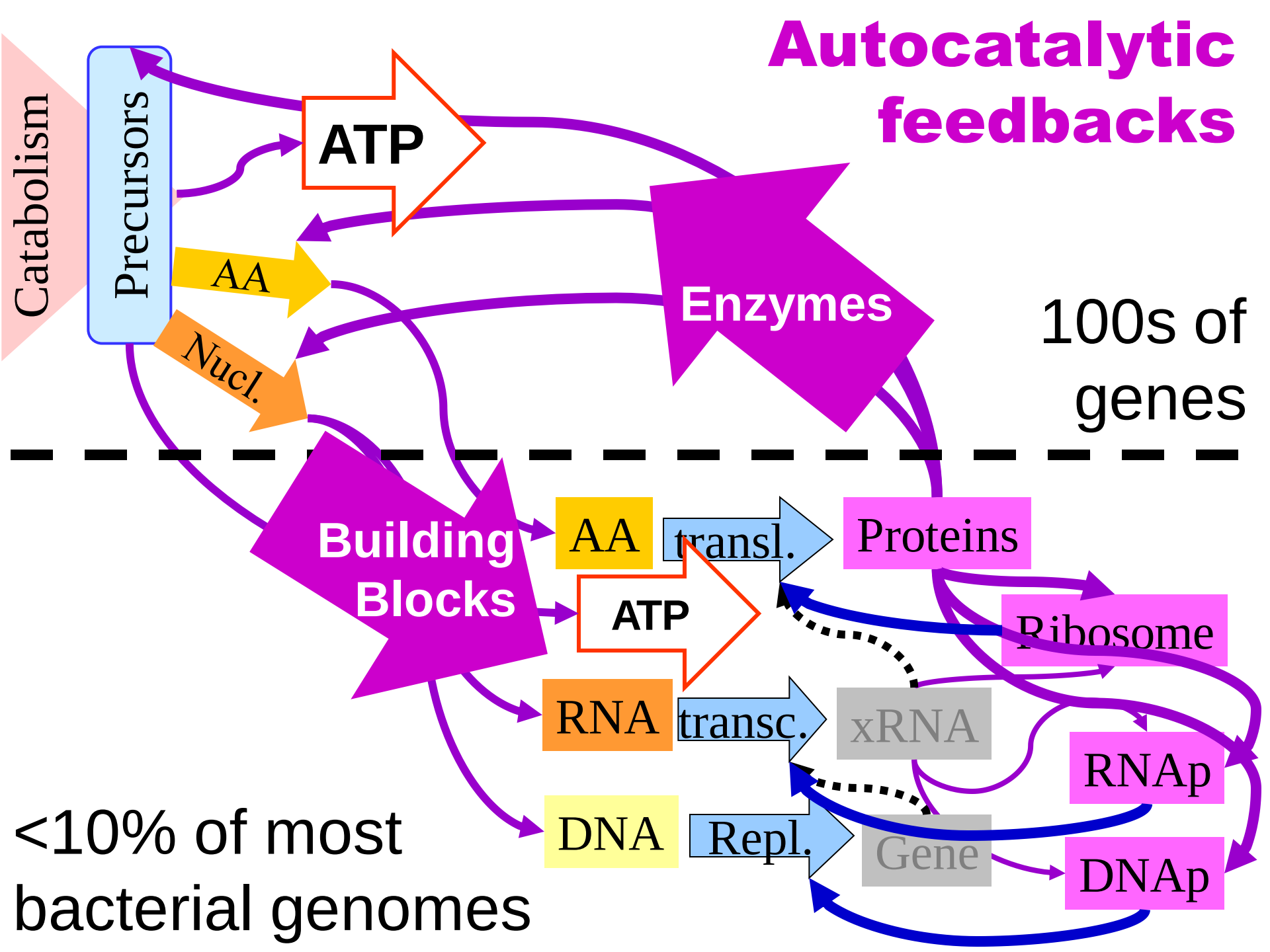
Crosslayer autocatalysis


Autocatalytic feedbacks
Catabolism
Precursors
ATP
AA
Nucl.
Enzymes
100s of genes
Building Blocks
AA
transl.
Proteins
ATP
Ribosome
RNA
transc.
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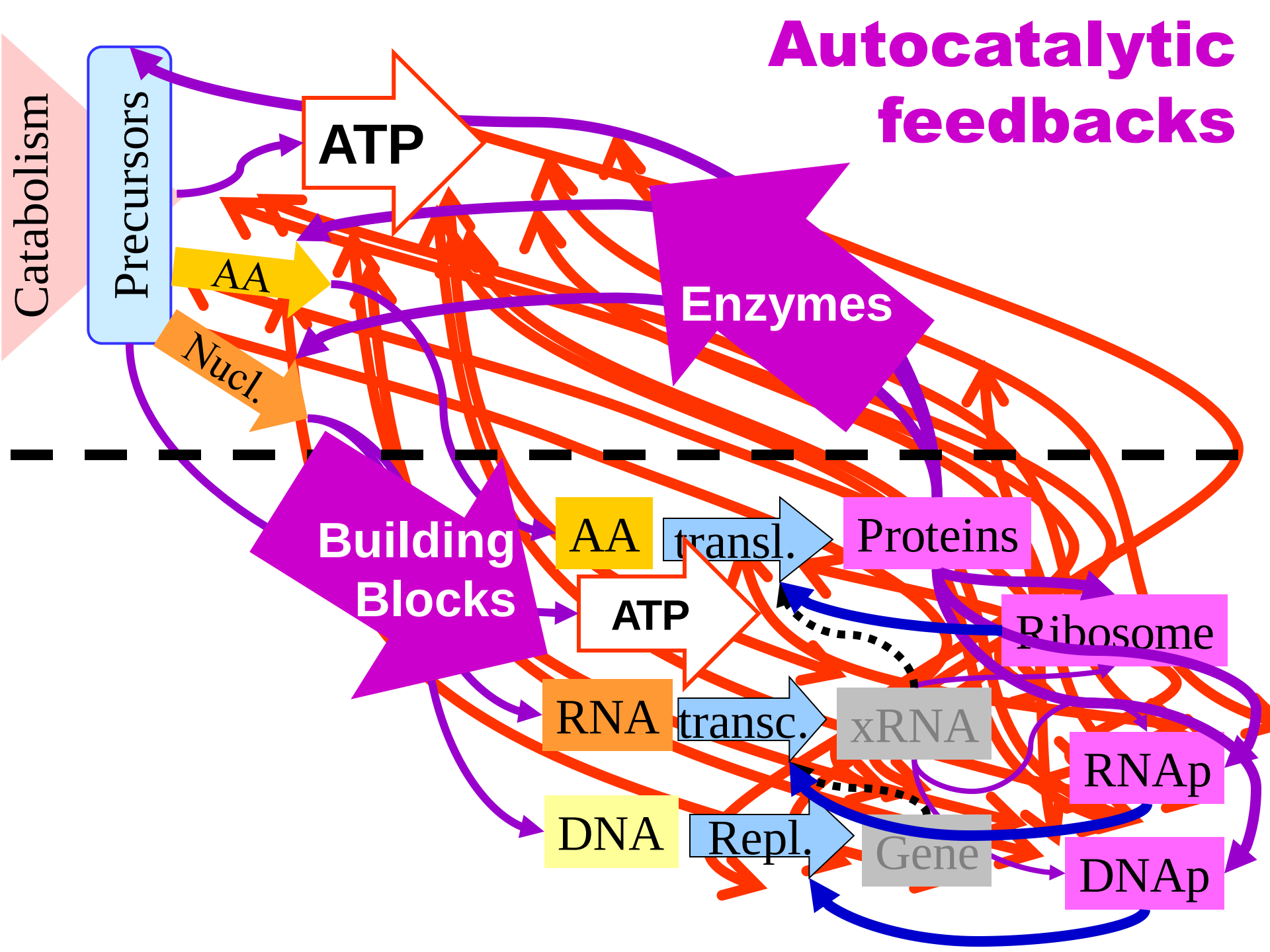
<10% of most bacterial genomes


Autocatalytic feedbacks
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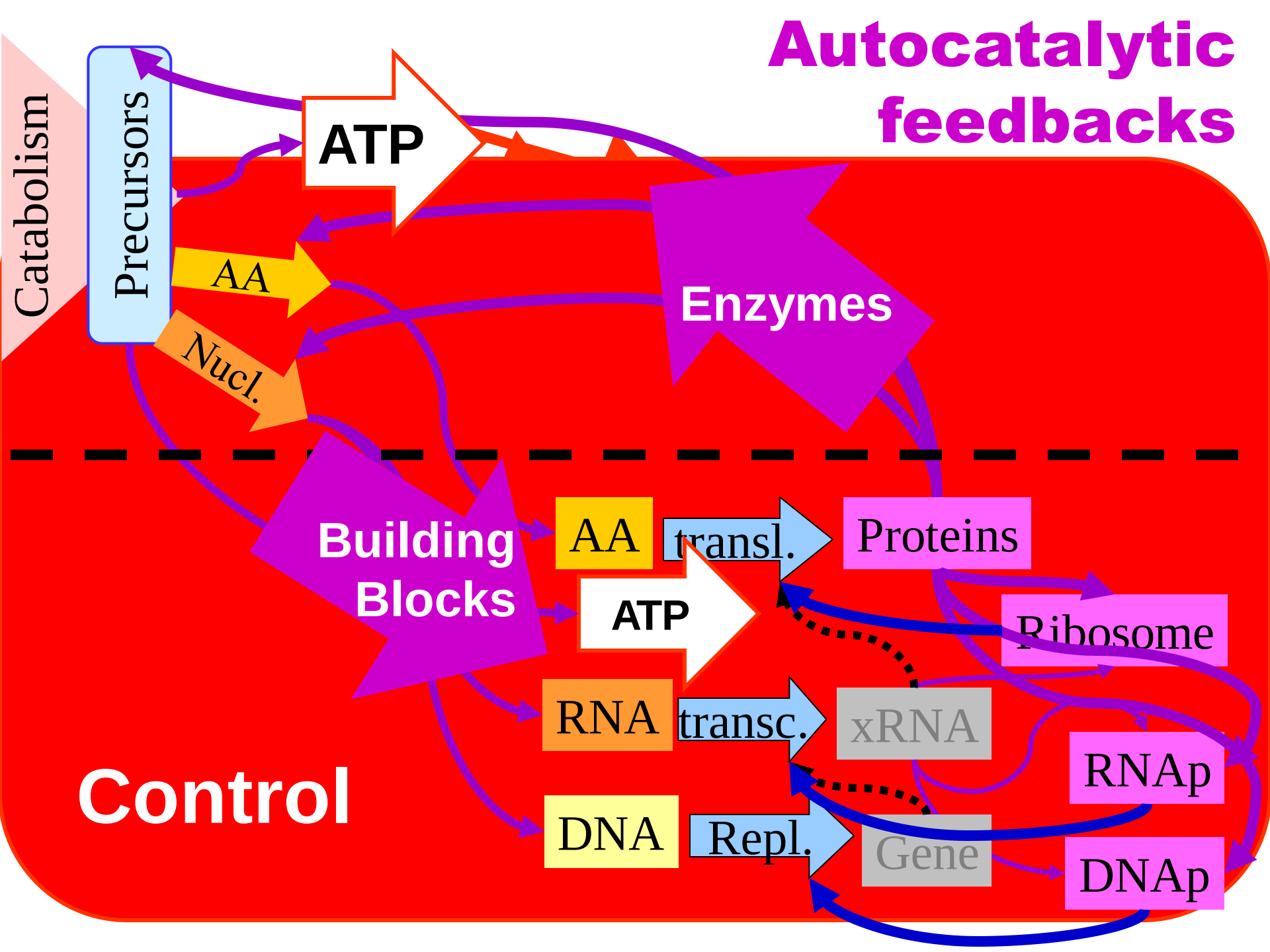
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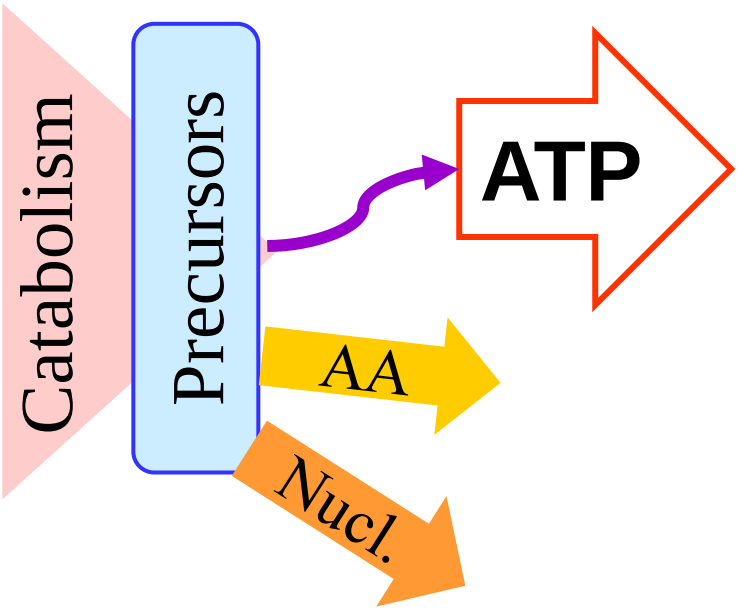
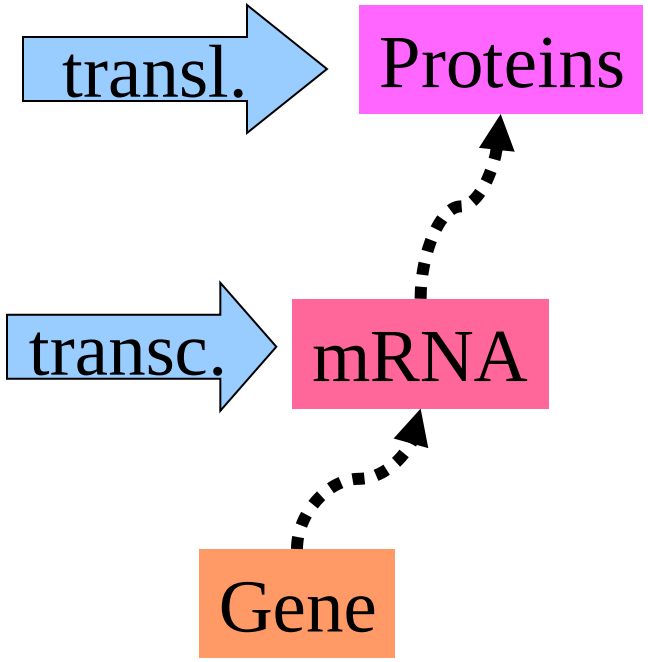
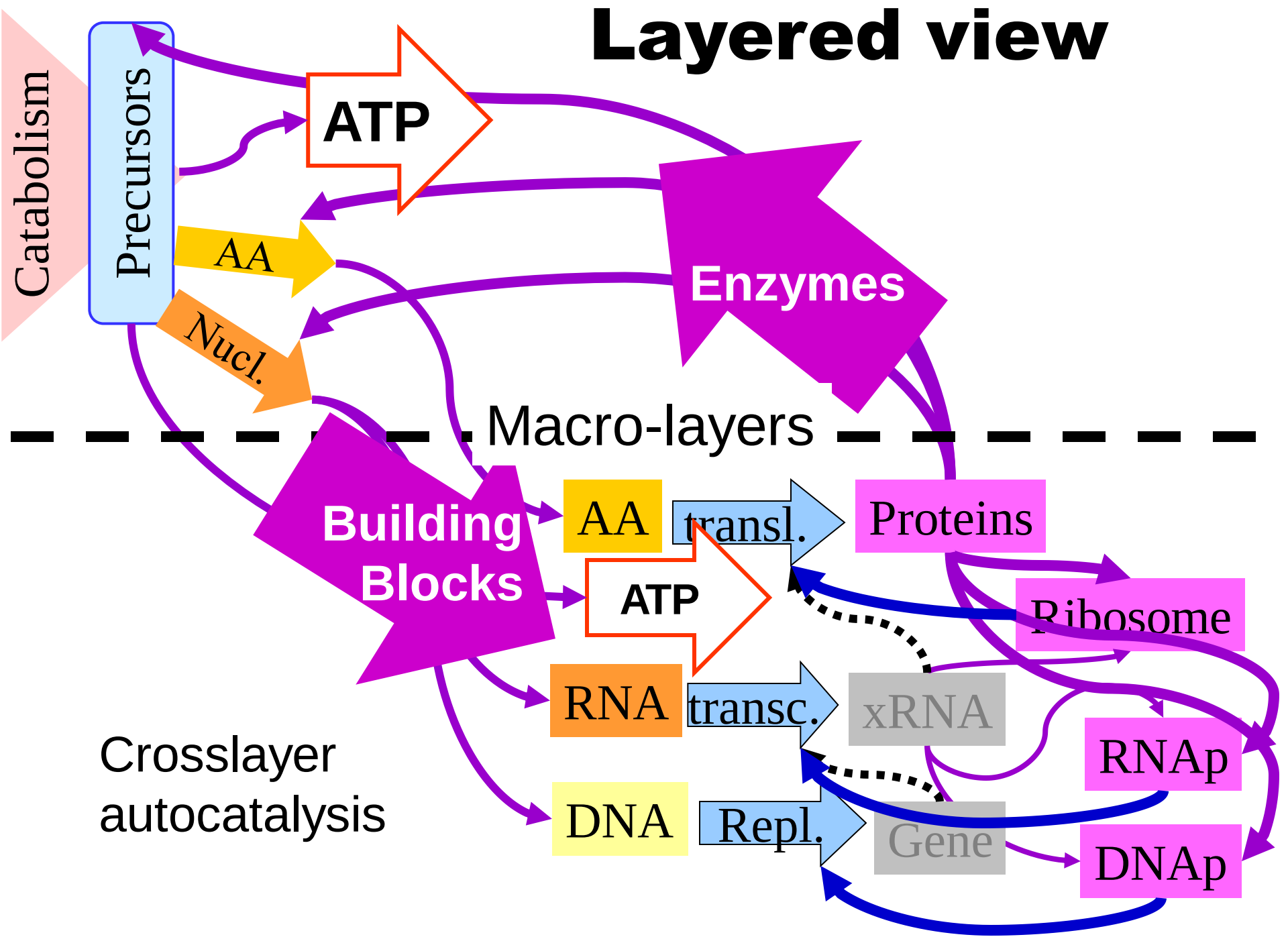


Pathway views

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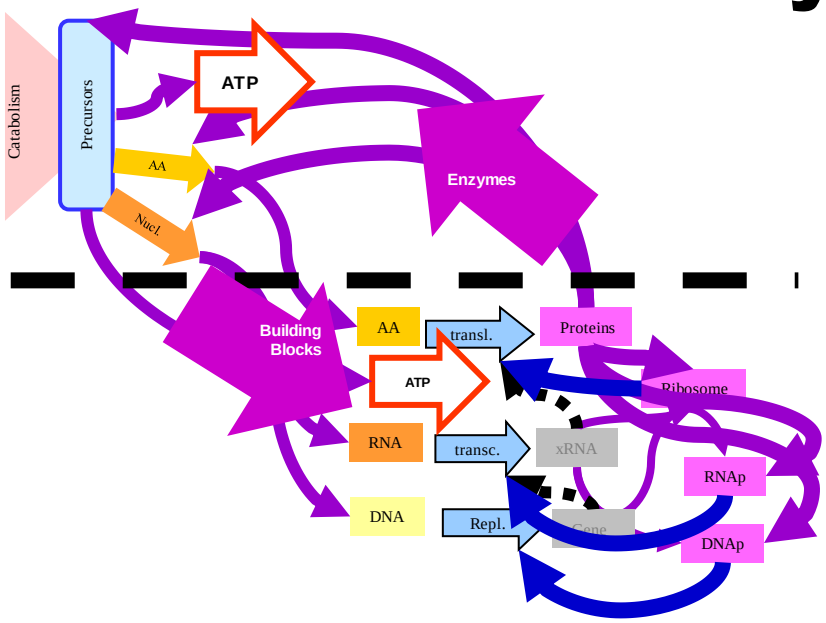
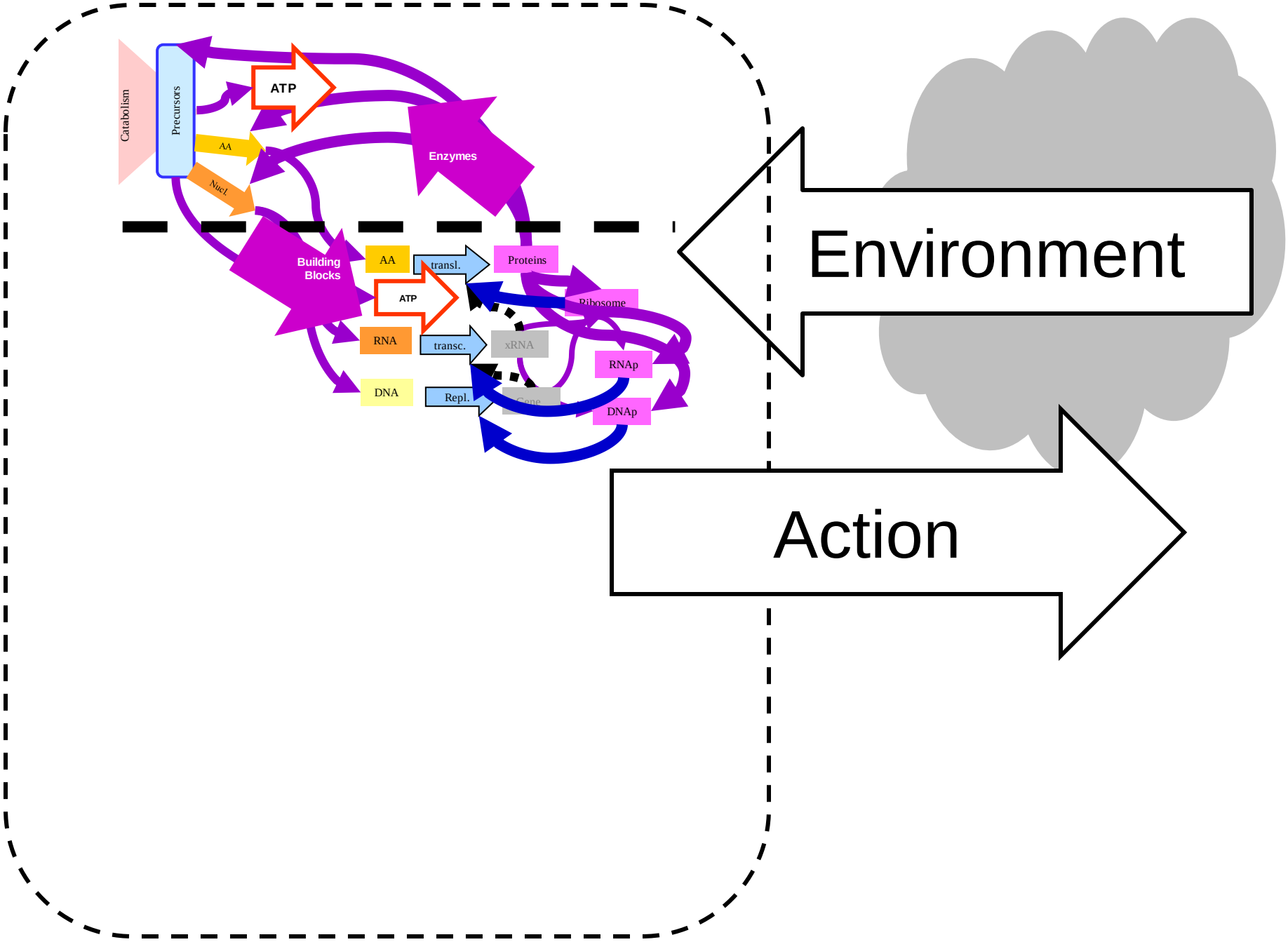
Layered view



<10% of most bacterial genomes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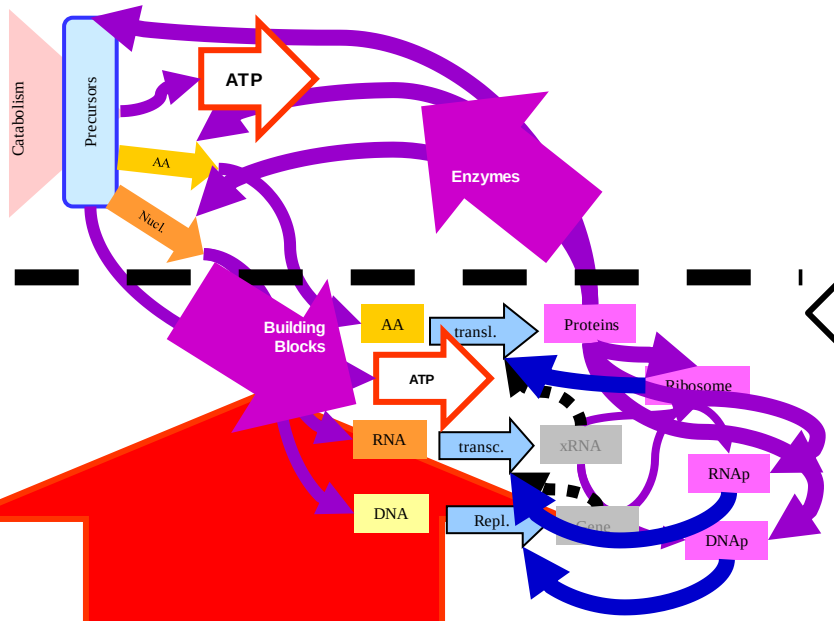
Gene
DNAp
Environment
Action



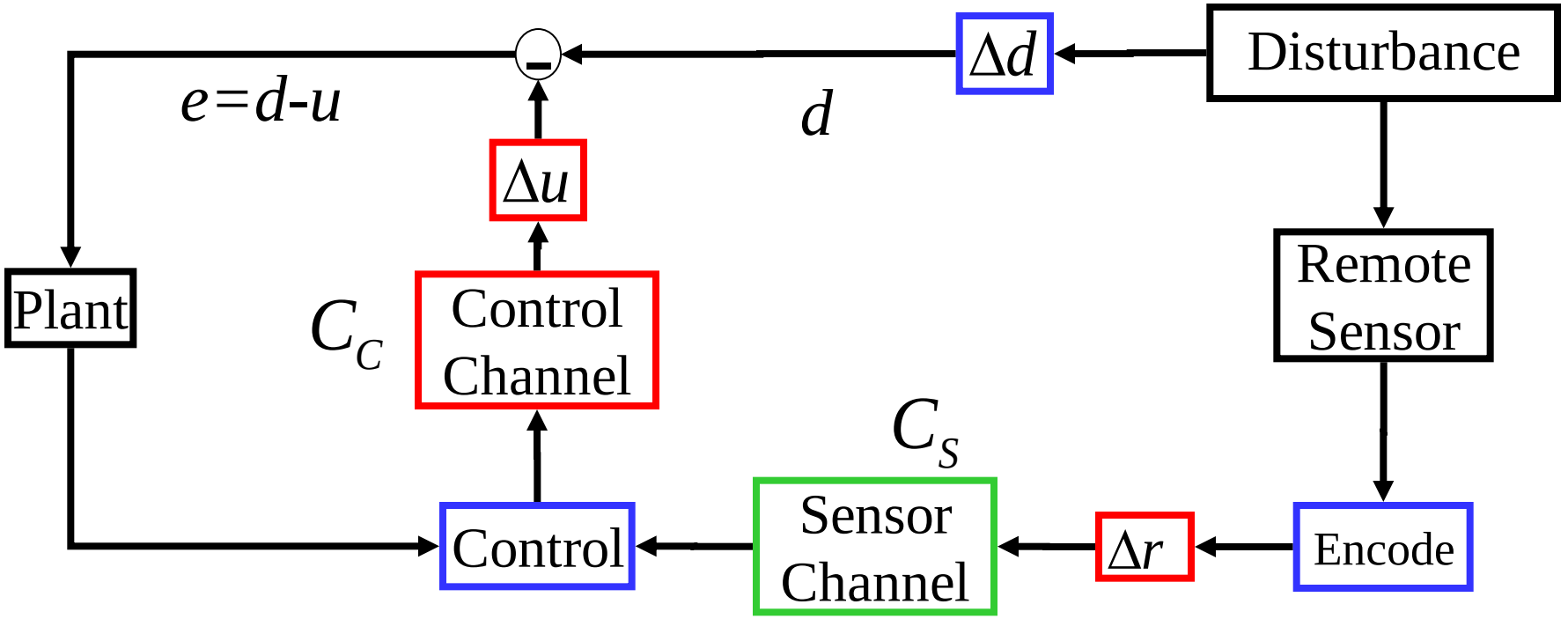
Environment

Action

Control

>90% of most bacterial genomes

Computing?
Communications?
Graphs?



benefits **stabilize**

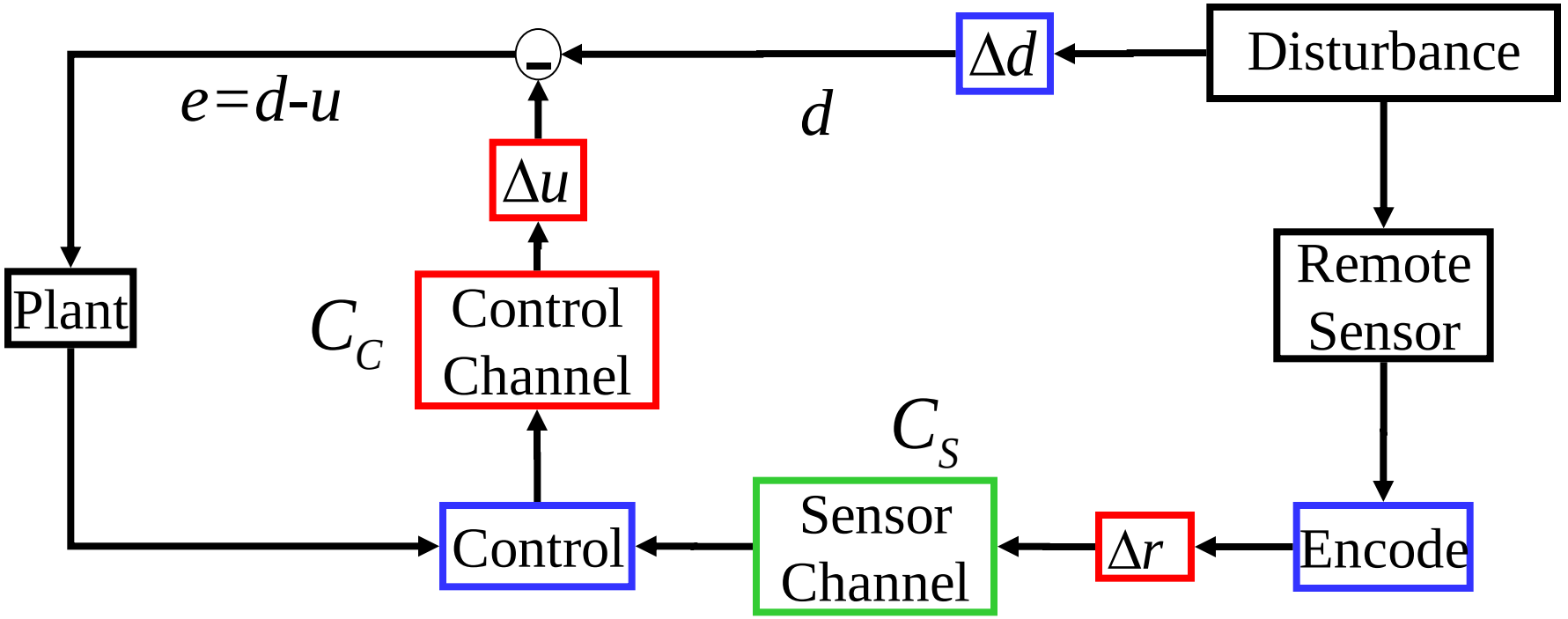
$$\int \left[\log|S|\right]_{-} d\omega \quad -\log(a) \geq$$

costs

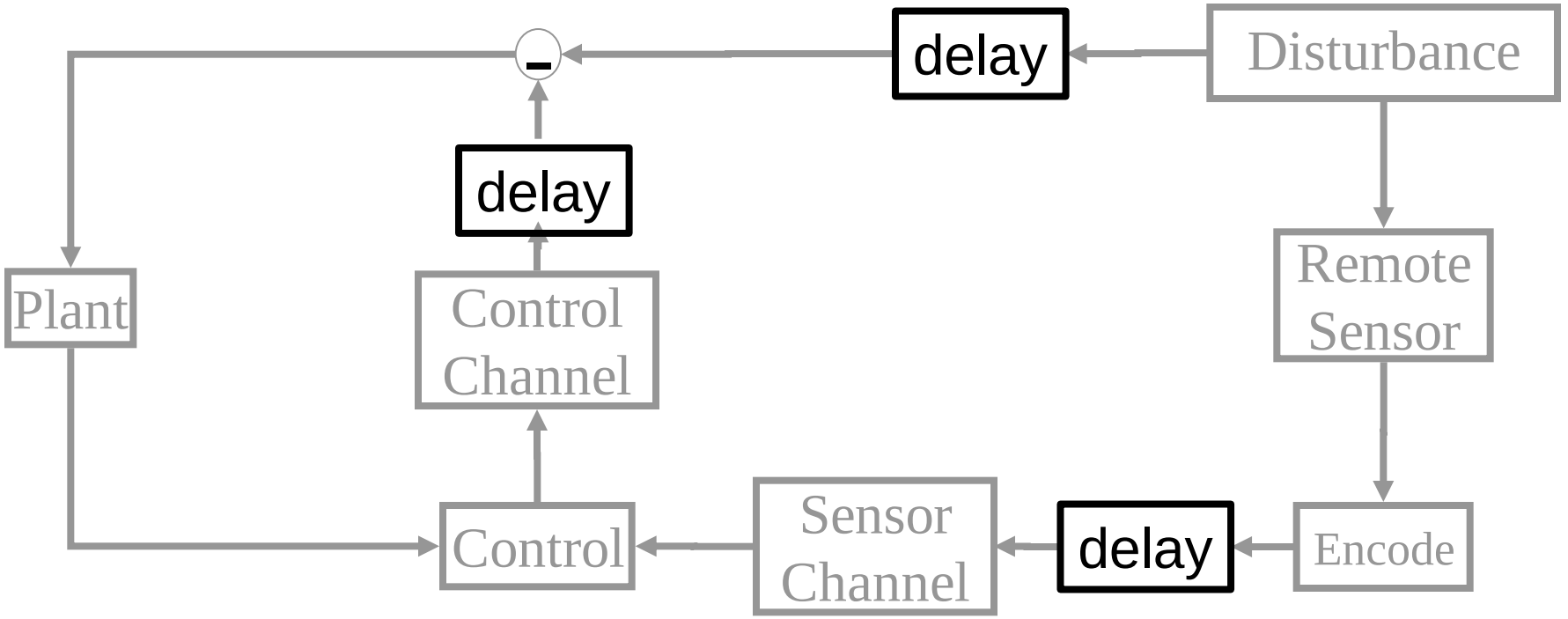
$$-C_C$$ **remote control**

$$-\int \left[\log|S|\right]_{+} d\omega \quad -C_S$$

feedback **remote sensing**

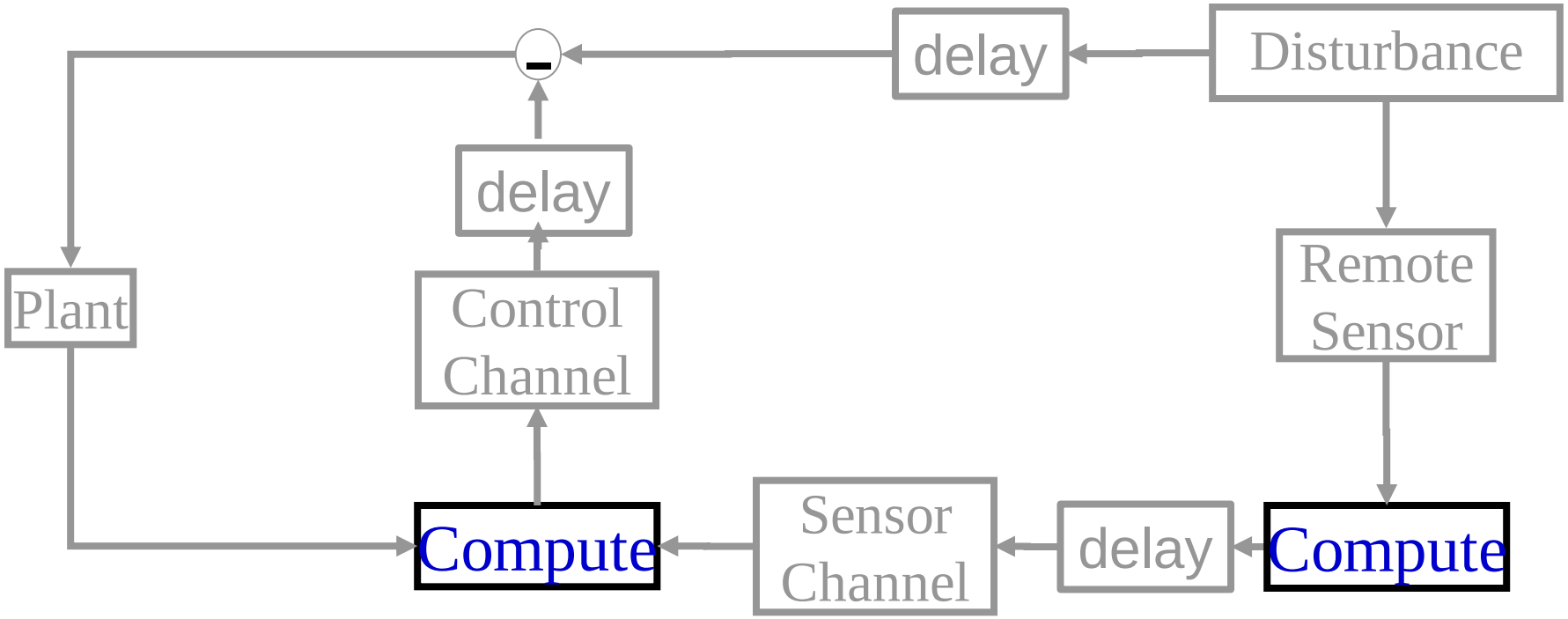


- Minimal toy diagram *vaguely* inspired by biology
- Has comms for control
- Signals and boxes not physiological (yet)
- **Naïve** use of theory from control, information, computation, graph, …. can be **misleading**

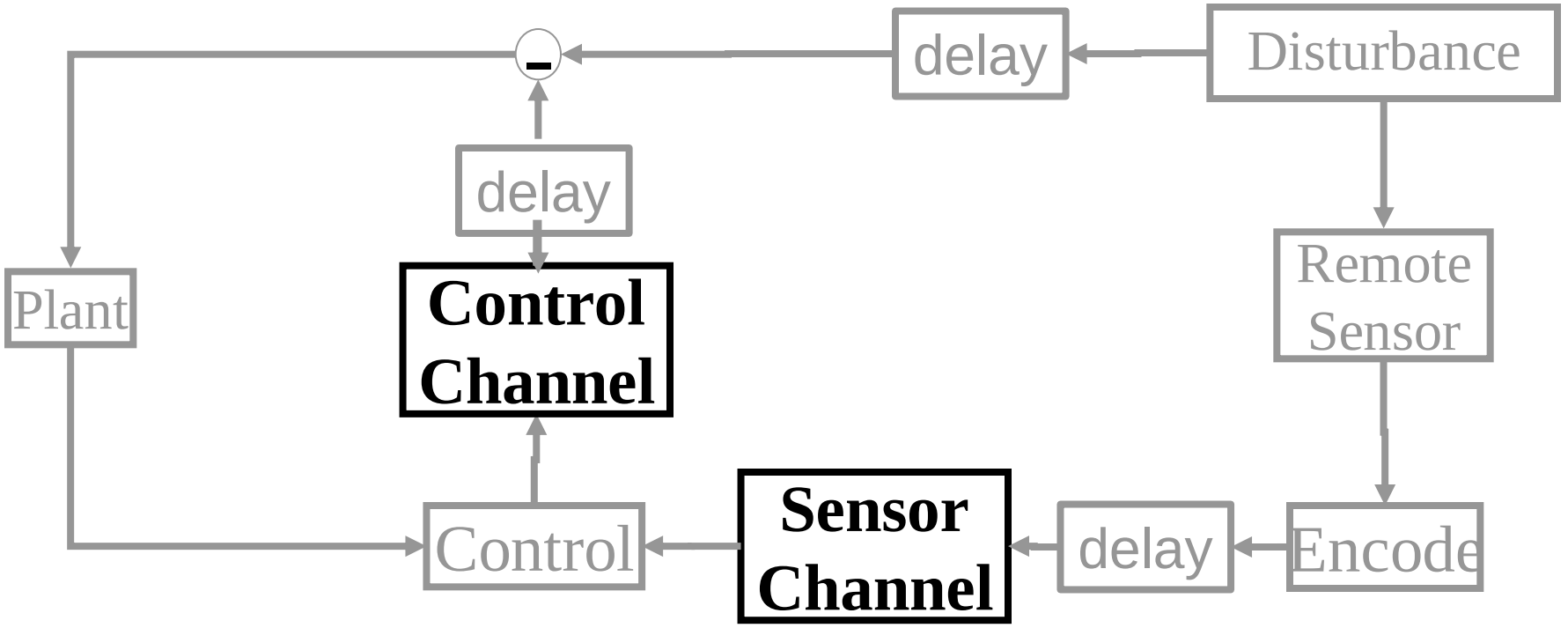


Delays everywhere

Pattern determines life or death



Computation everywhere
Distributed
Low latency required
Not Turing/VonNeumann architecture



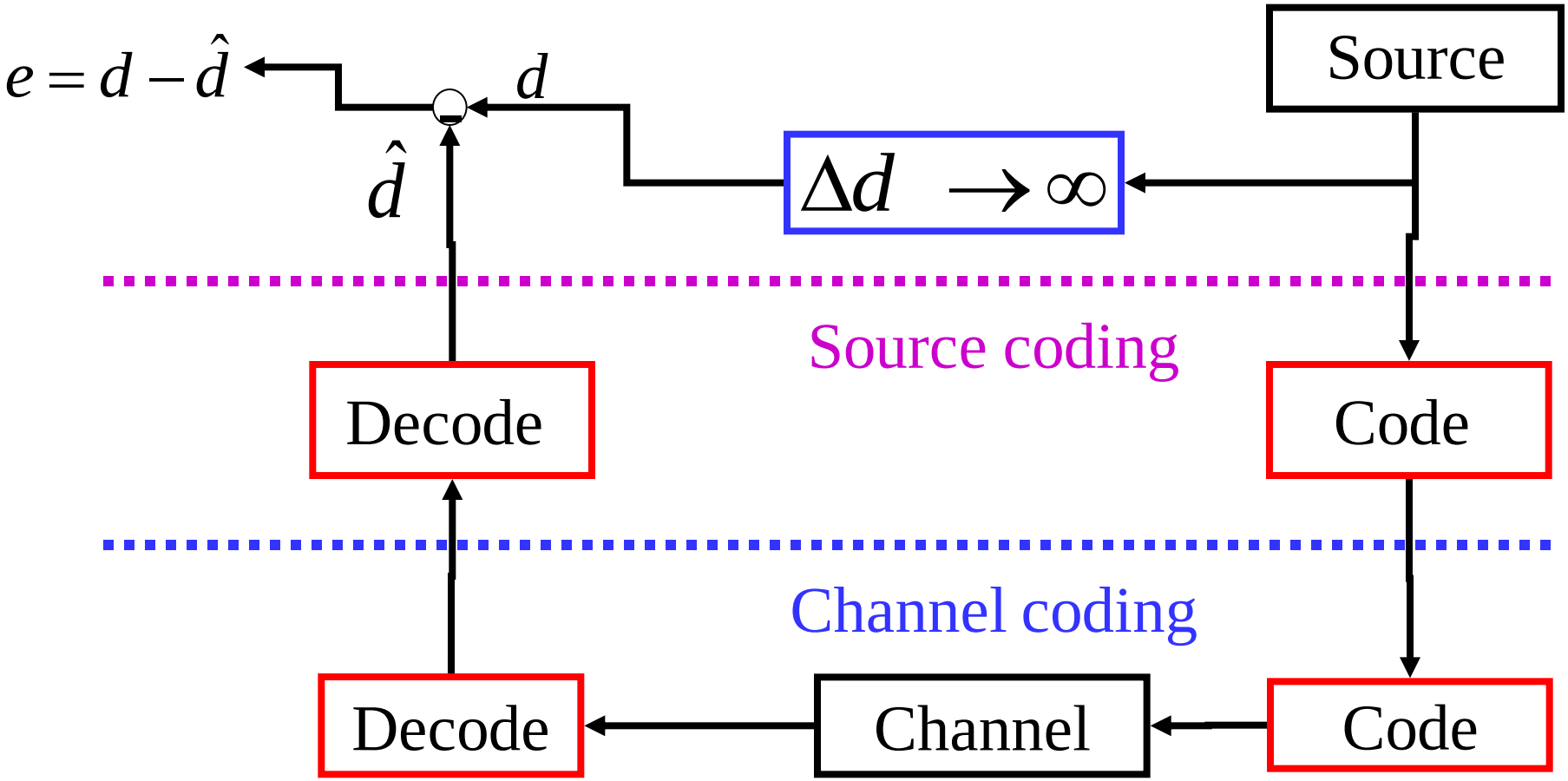
Noisy communication everywhere
Low latency required
Not Shannon architecture (source+channel)

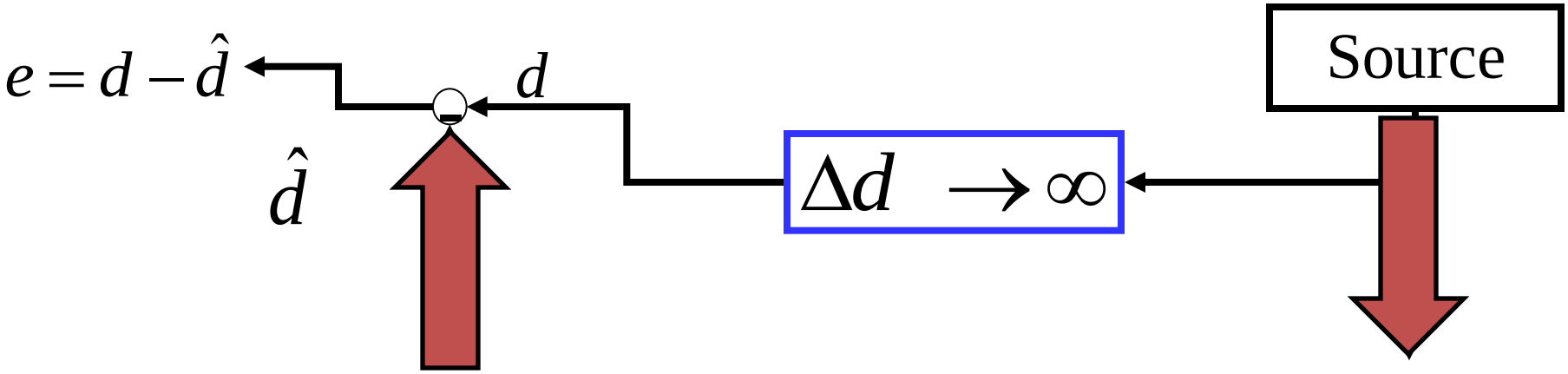
Layering coding

- This is just a very simple interpretation of source and channel coding as a layered architecture
- Adds nothing but motivates comparison with other layered structures

1. Bounds
2. Achievability
3. **Decomposition/ Layering**

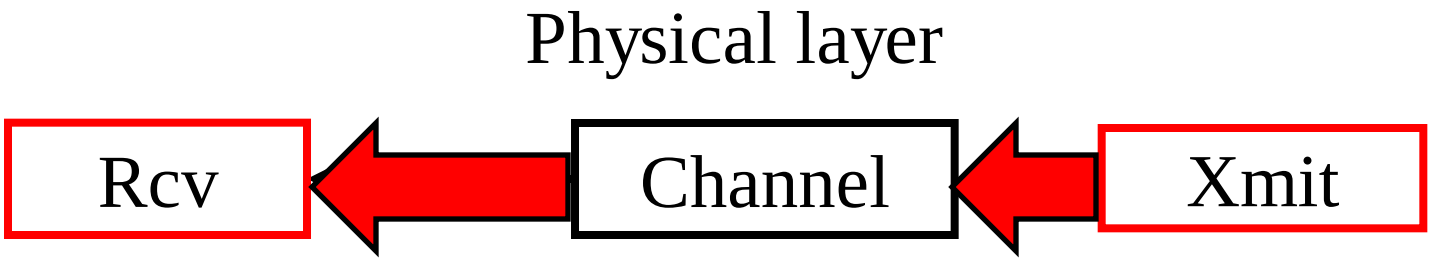
Optimal coding can have a "trivial" layered implementation.



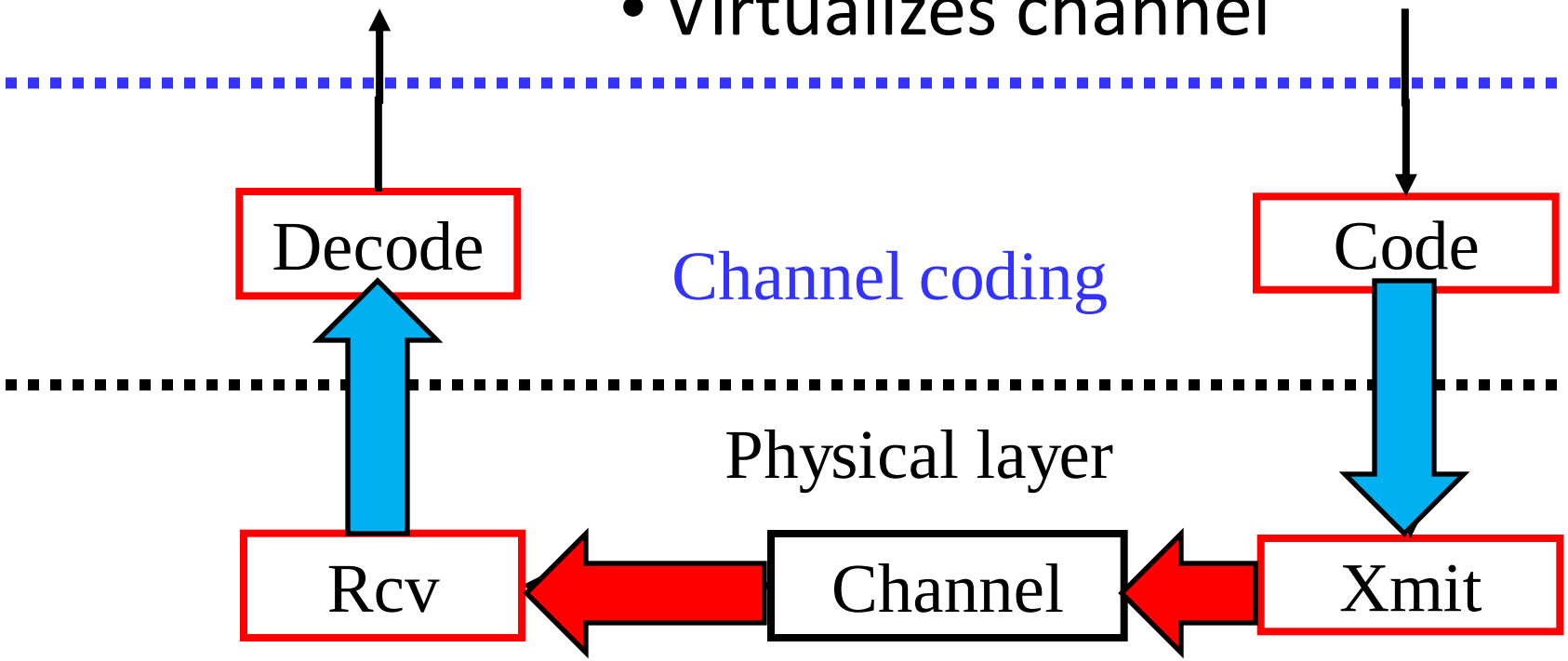


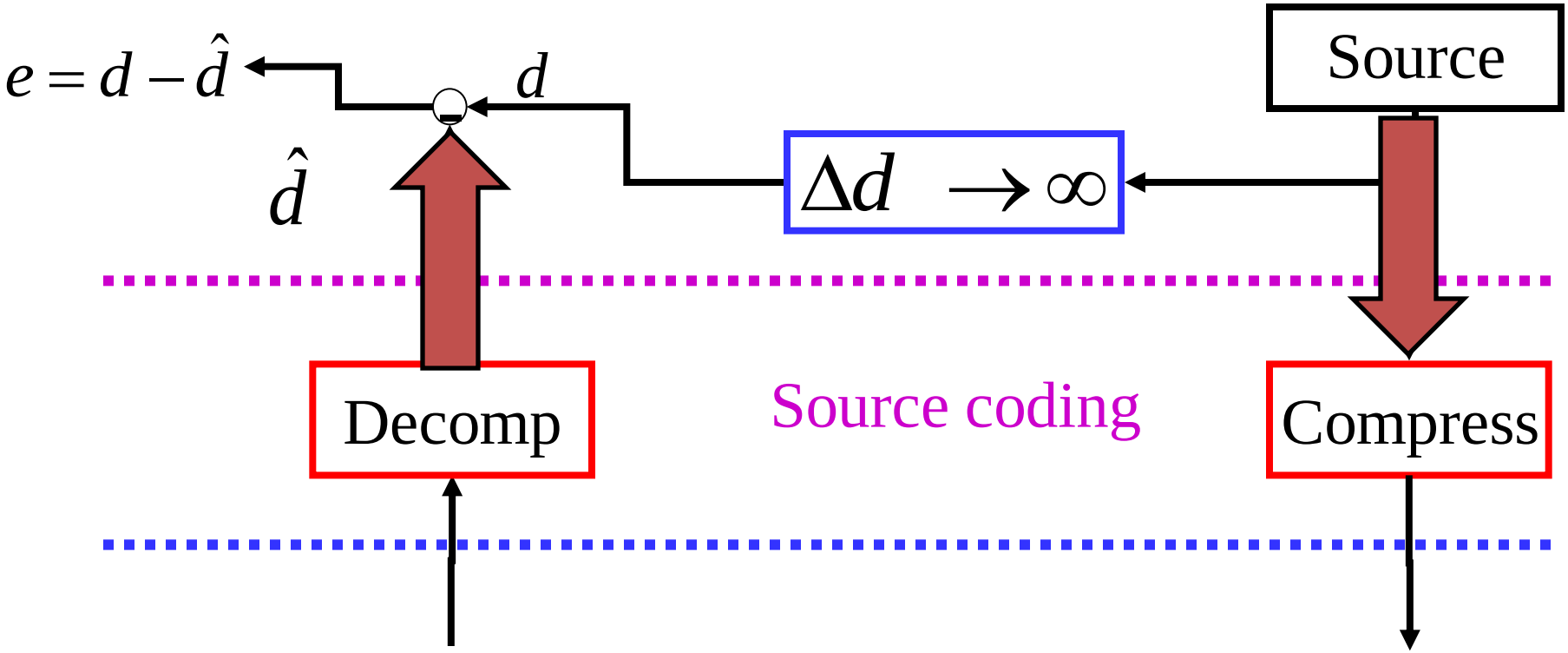
Start with

- a system level constraint from application layer
- the component level constraint from physical layer

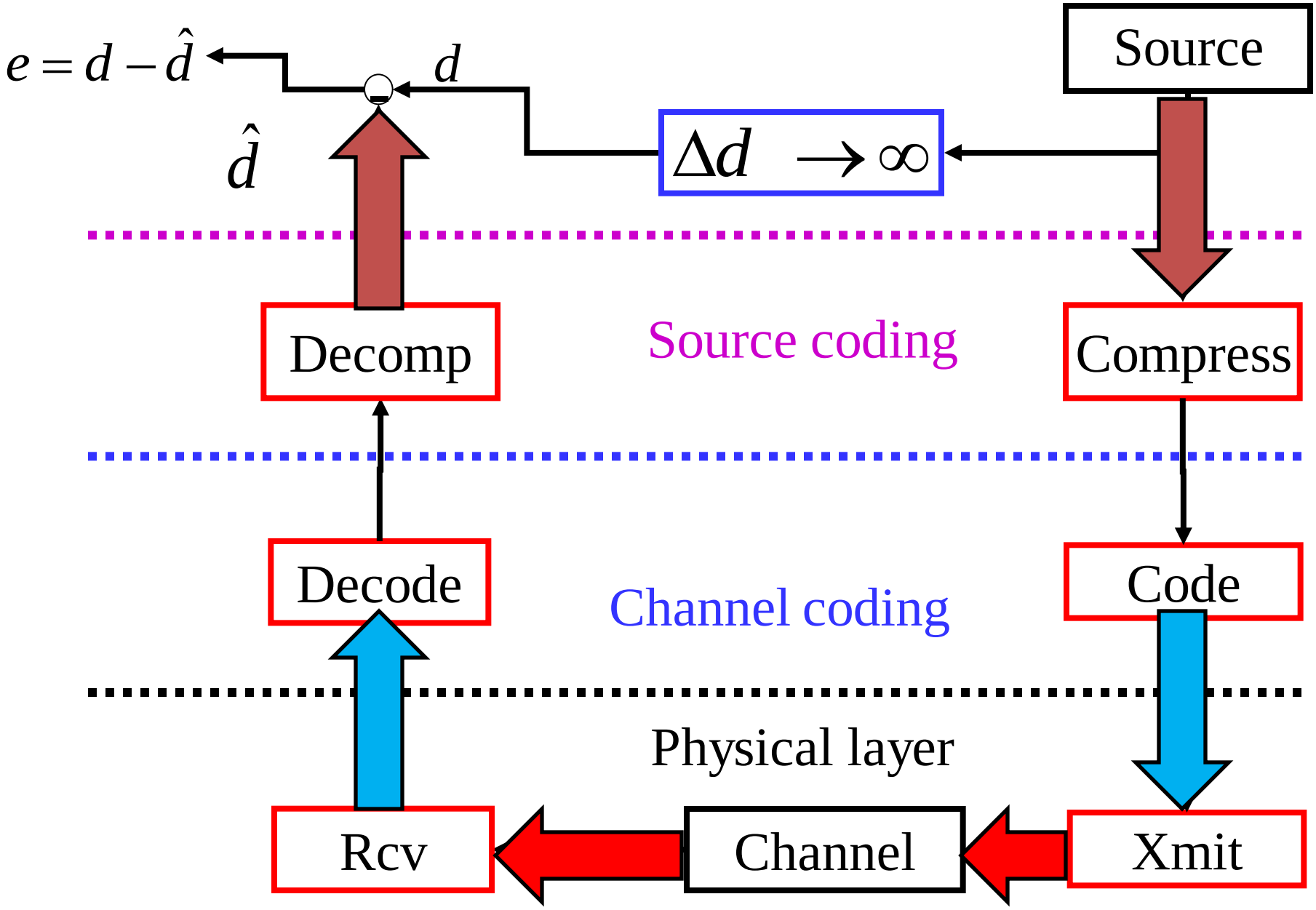


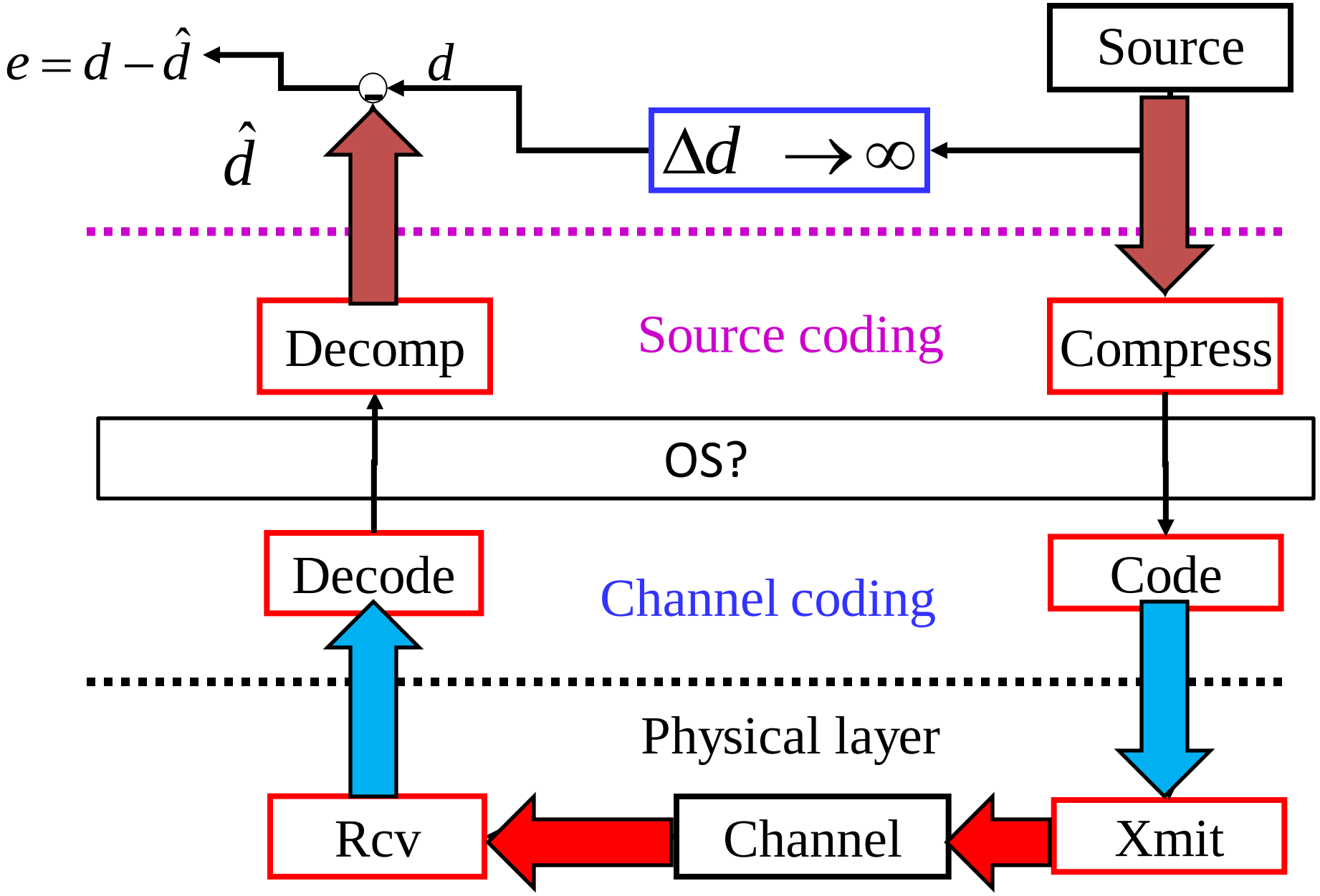
- Decoupled
- Hides details
- Virtualizes channel





- Decoupled
- Hides details
- Virtualizes source


$e = d - \hat{d}$
d
$\hat{d}$
Source
$\Delta d \rightarrow \infty$
Decomp
Source coding
Compress
Decode
Channel coding
Code
Physical layer
Rcv
Channel
Xmit


$e = d - \hat{d}$
d
$\hat{d}$
Source
$\Delta d \rightarrow \infty$
Decomp
Source coding
Compress
OS?
Decode
Channel coding
Code
Physical layer
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Channel
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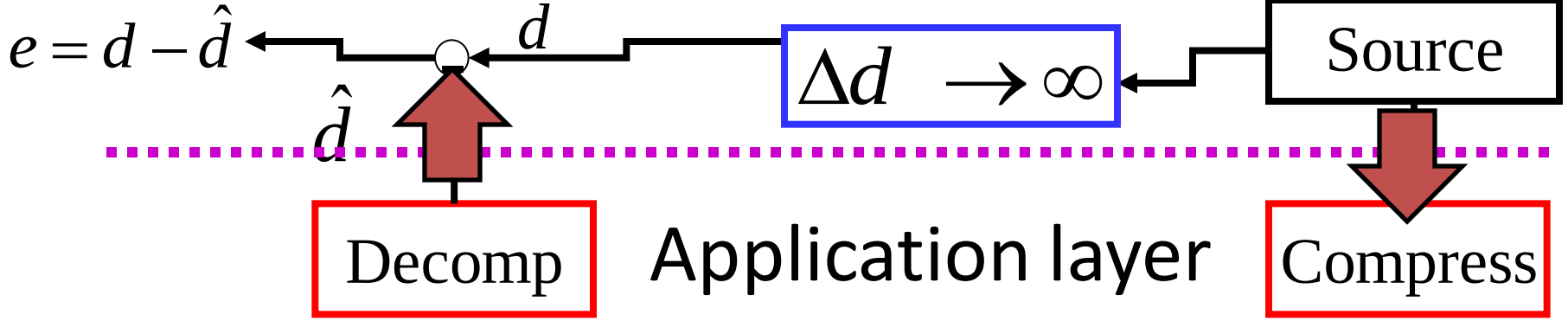
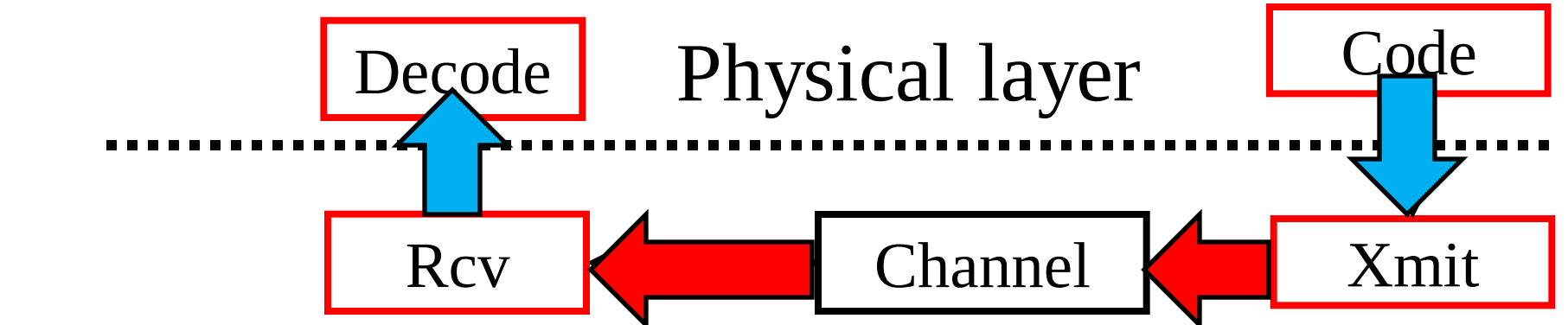
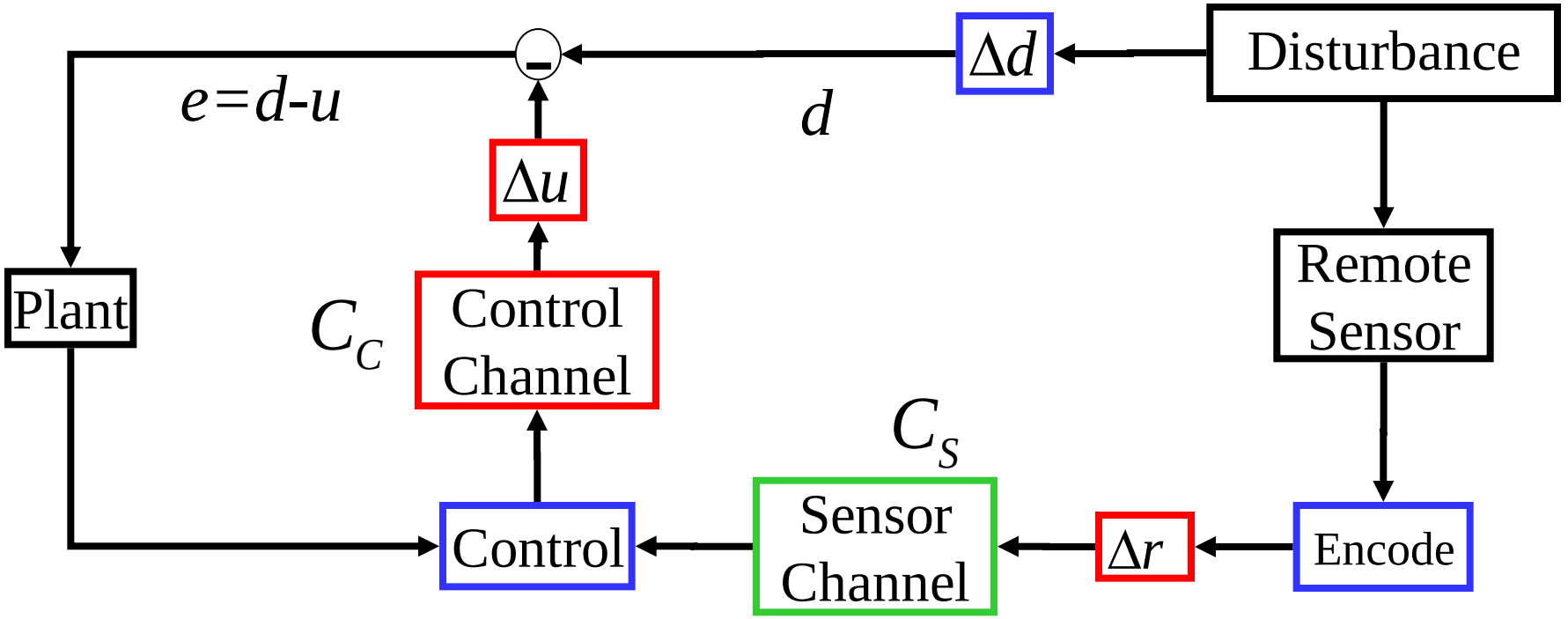


Internet= Distributed OS

Layered architecture

Control theory





benefits **stabilize**

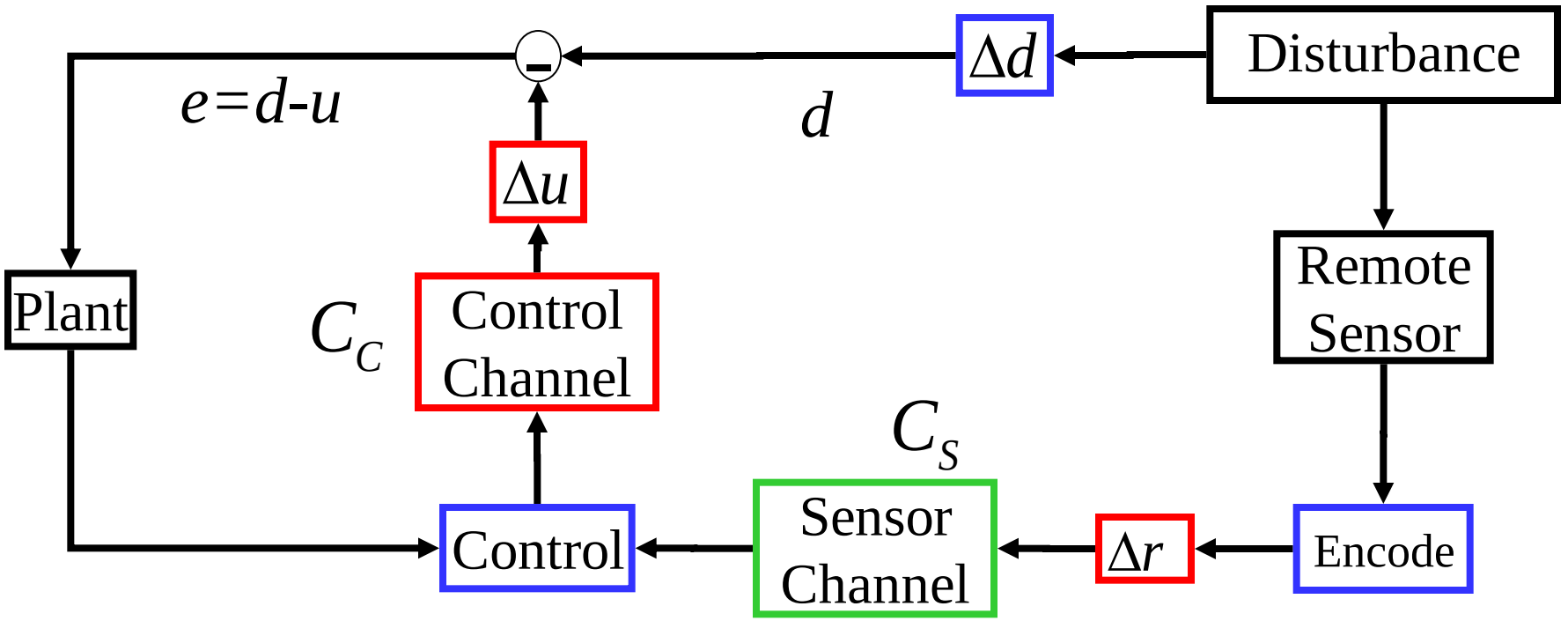
$$\int \left[\log|S|\right]_{-} d\omega \quad -\log(a) \geq$$

costs

$$-C_C$$ **remote control**

$$-\int \left[\log|S|\right]_{+} d\omega \quad -C_S$$

feedback **remote sensing**



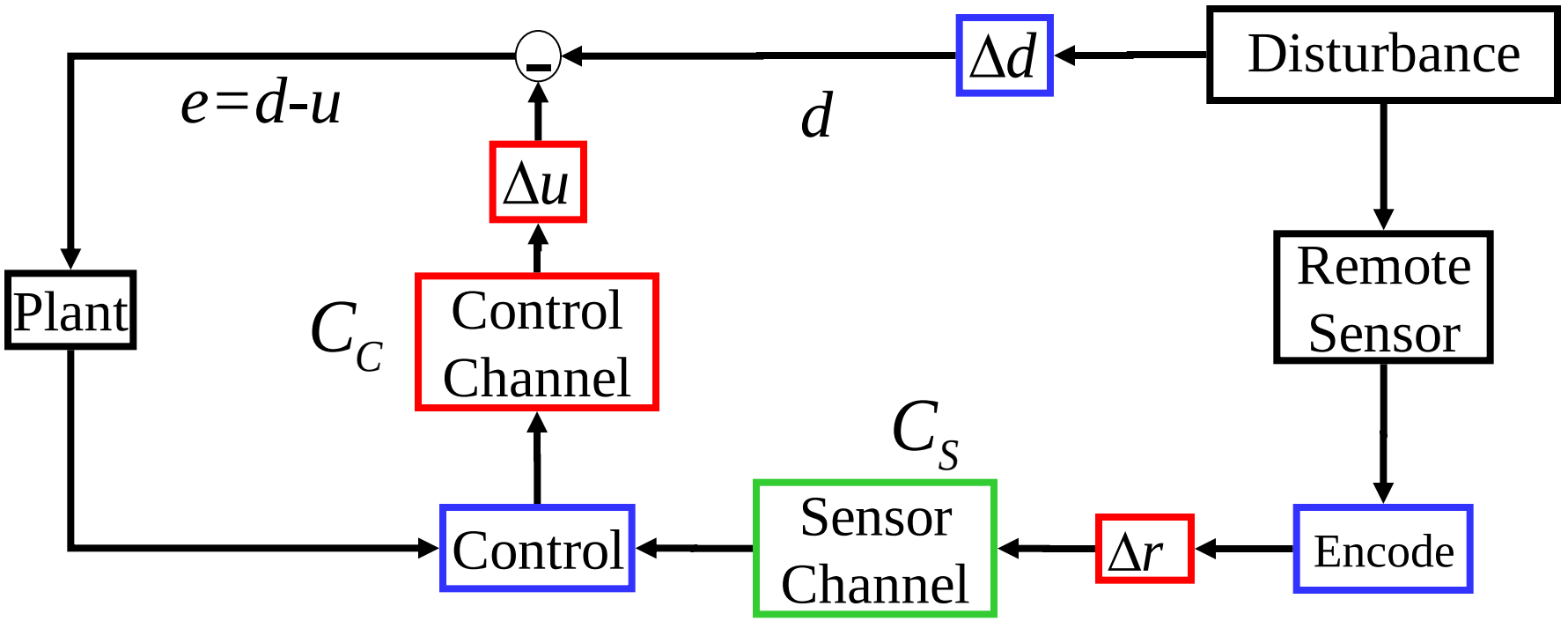
benefits

$$\int \lceil \log |S| \rceil_{-} \, d\omega$$

feedback

$-C_S$

remote sensing



stabilize

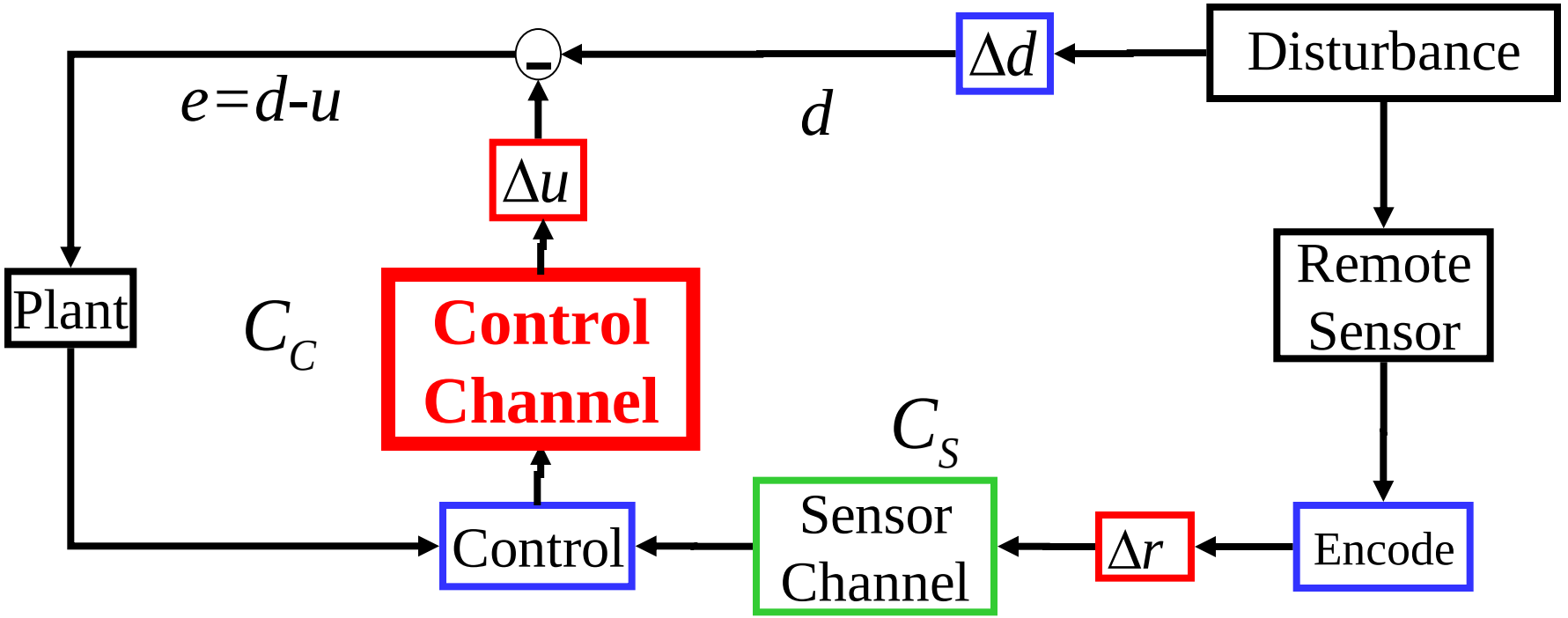
$$-\log(a) \geq$$

feedback

$$-\int \left[\log|S|\right]_+ d\omega$$

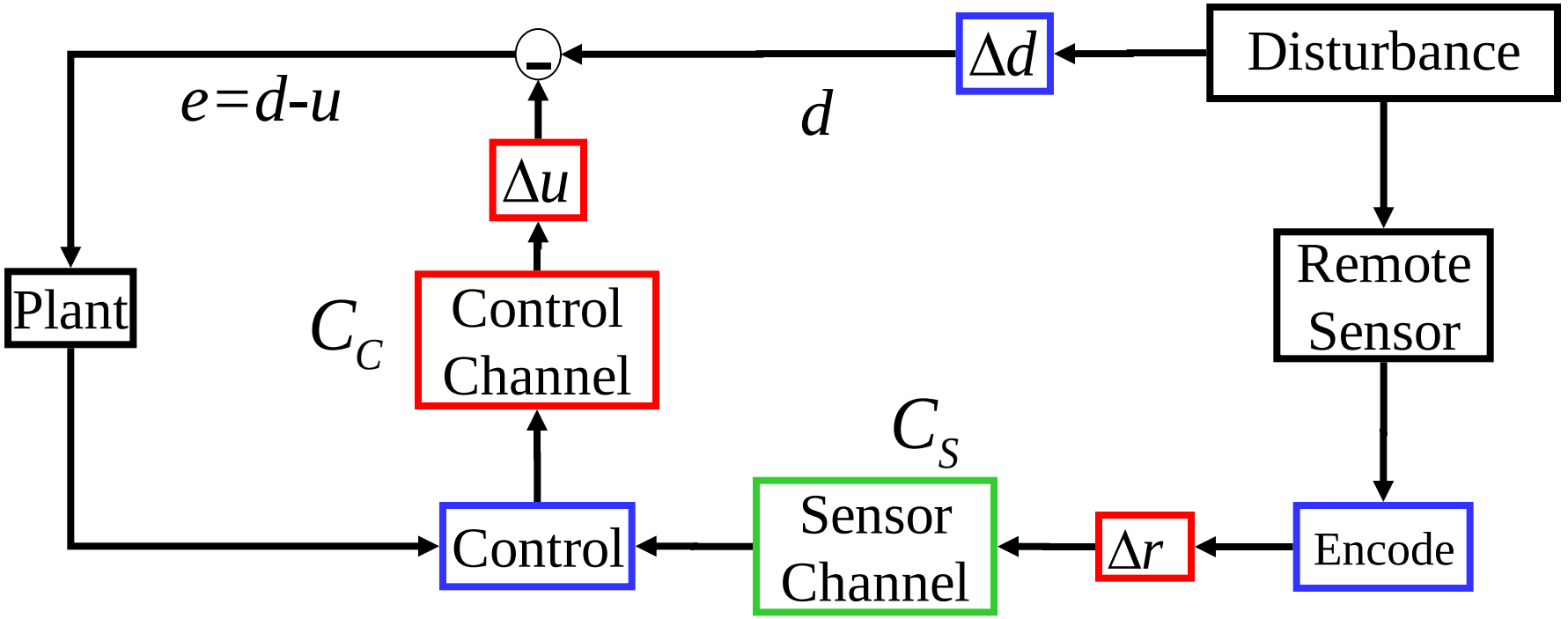
feedback

costs



$-C_C$ **remote control**

costs



benefits **stabilize**

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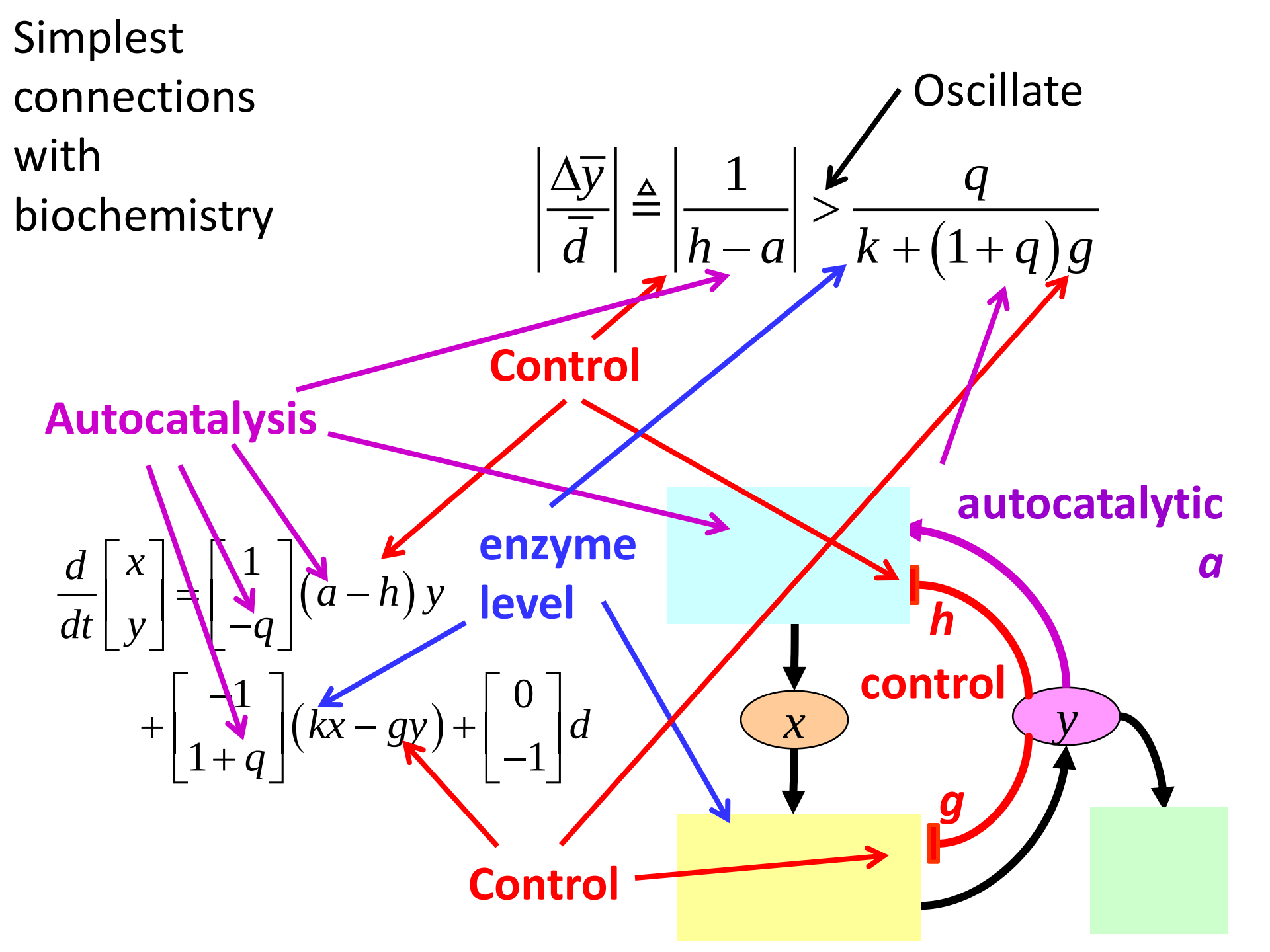
costs

$$-C_C$$ **remote control**

$$-\int \left[\log|S|\right]_{+} d\omega \quad -C_S$$

feedback **remote sensing**

Simplest connections with biochemistry



Deeper connections

Theorem

$$\frac{1}{\pi}\int_0^{\infty} \ln\left|S(j\omega)\right|\left(\frac{z}{z^2+\omega^2}\right)d\omega \geq \ln\left|\frac{z+p}{z-p}\right|$$

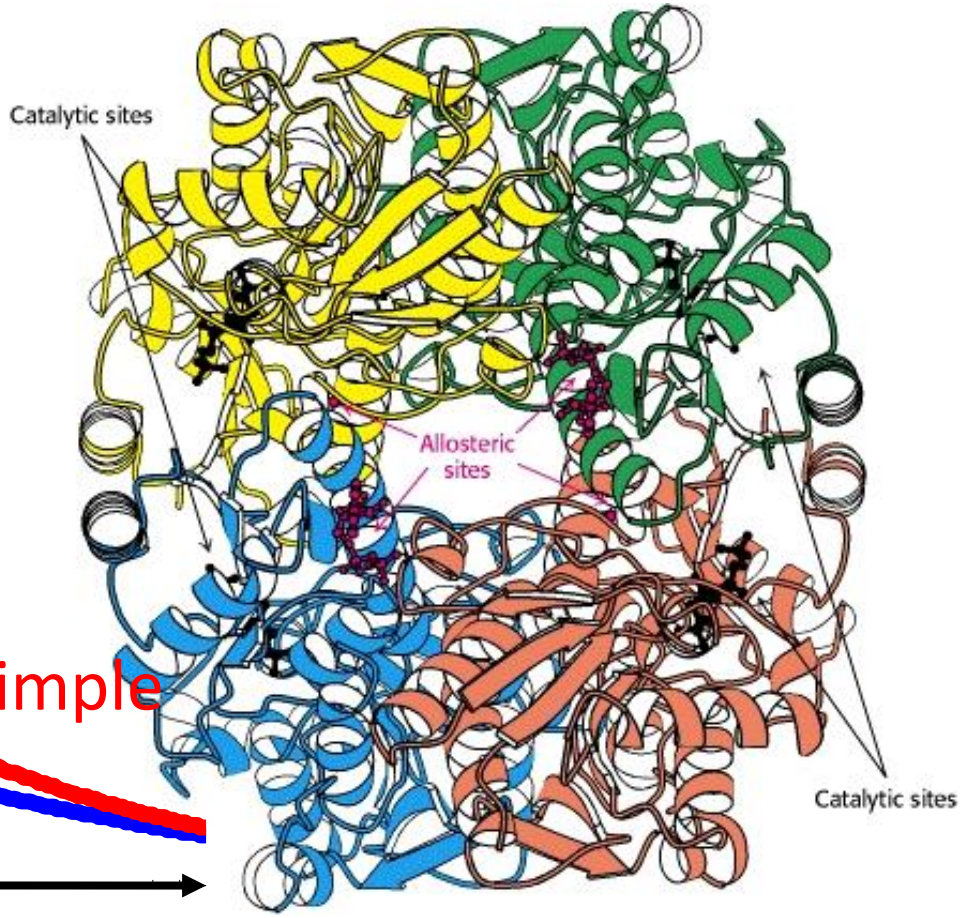
Fragility

hard limits

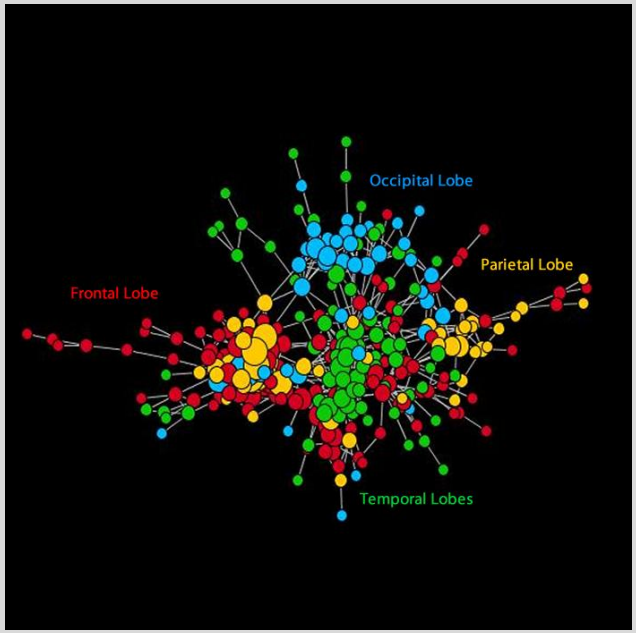
simple

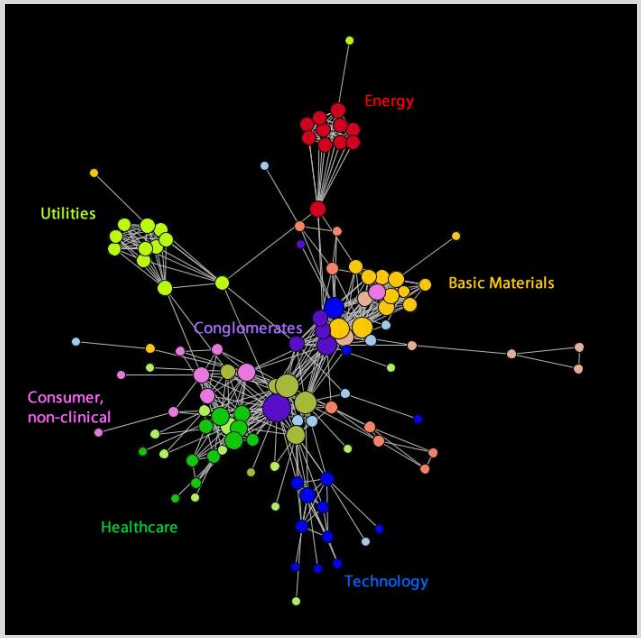
complex

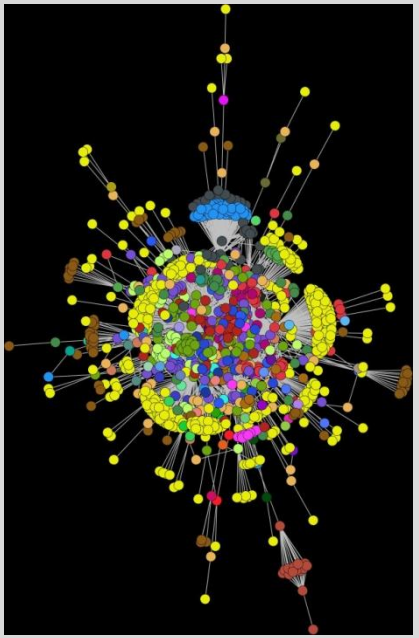
Overhead, waste



What's special and what's not so special about human brains compared to other information networks?



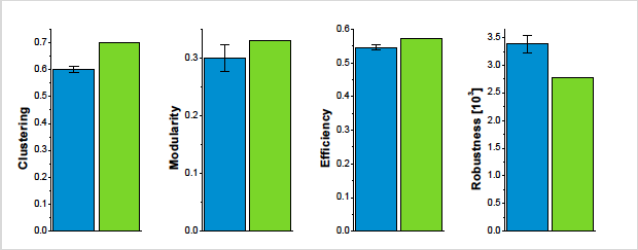




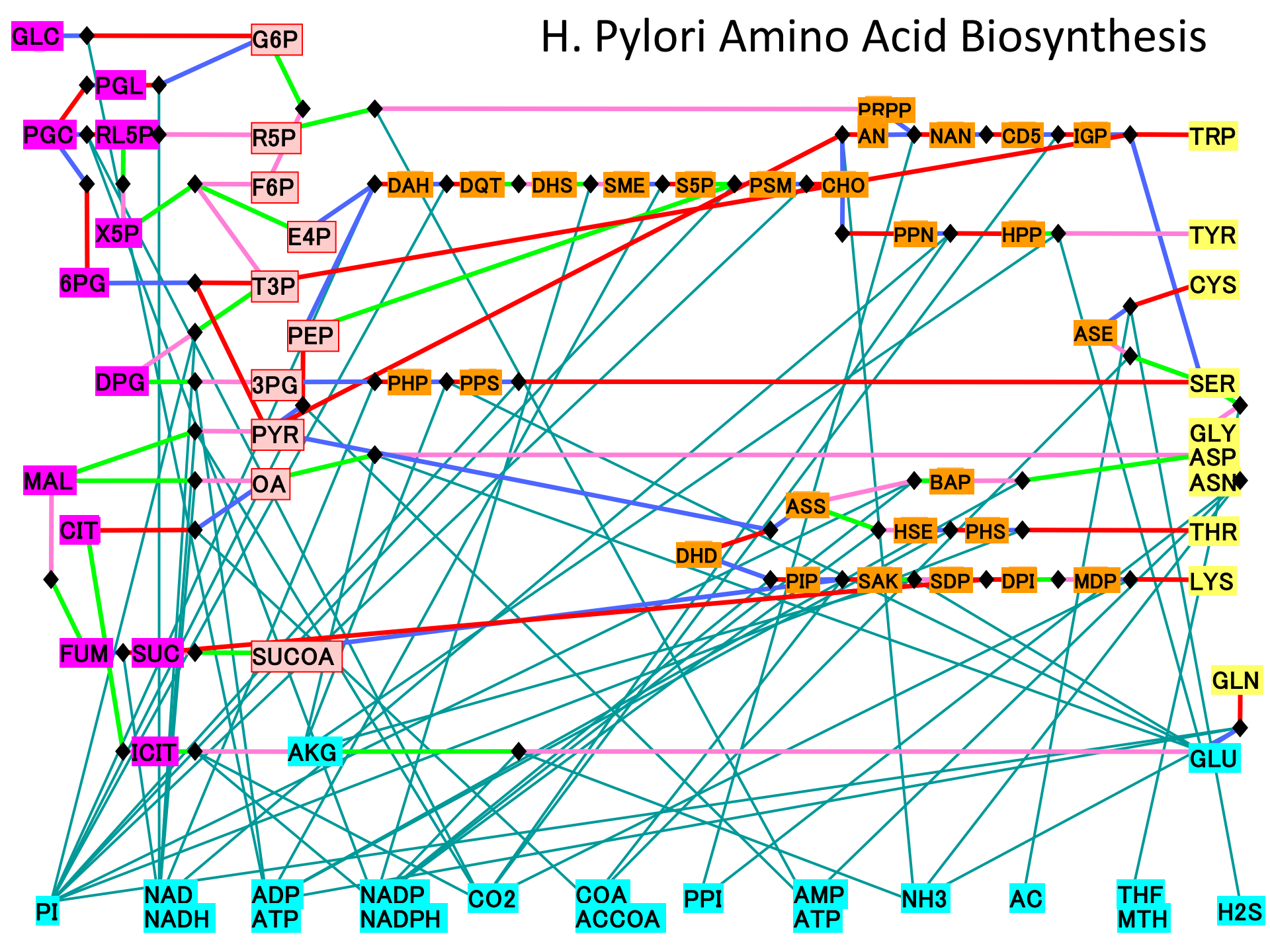
Human Brain Network
Resting state FMRI

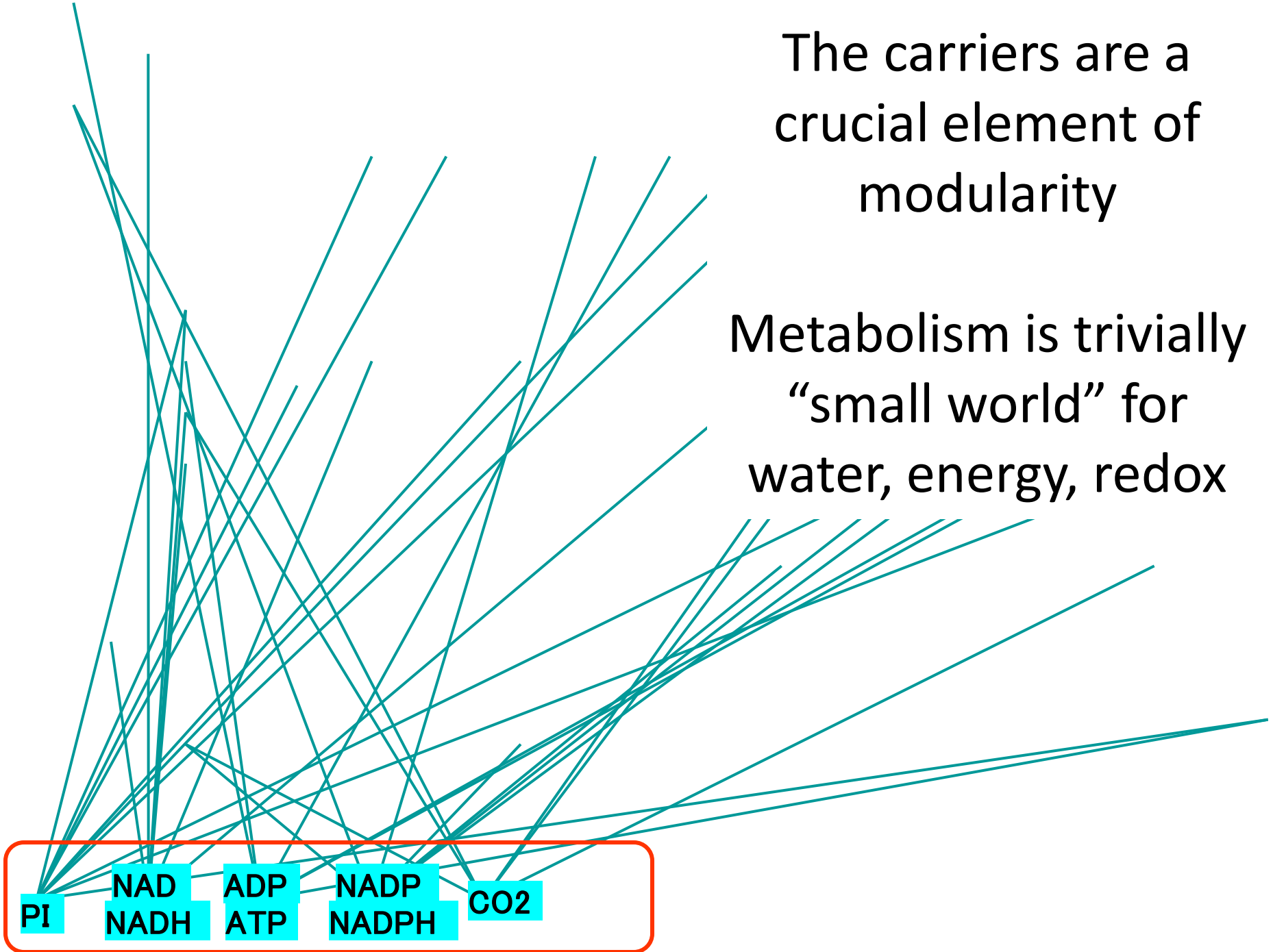
Economic Network
New York Stock Exchange

Social Network
Twitter #gadaffi



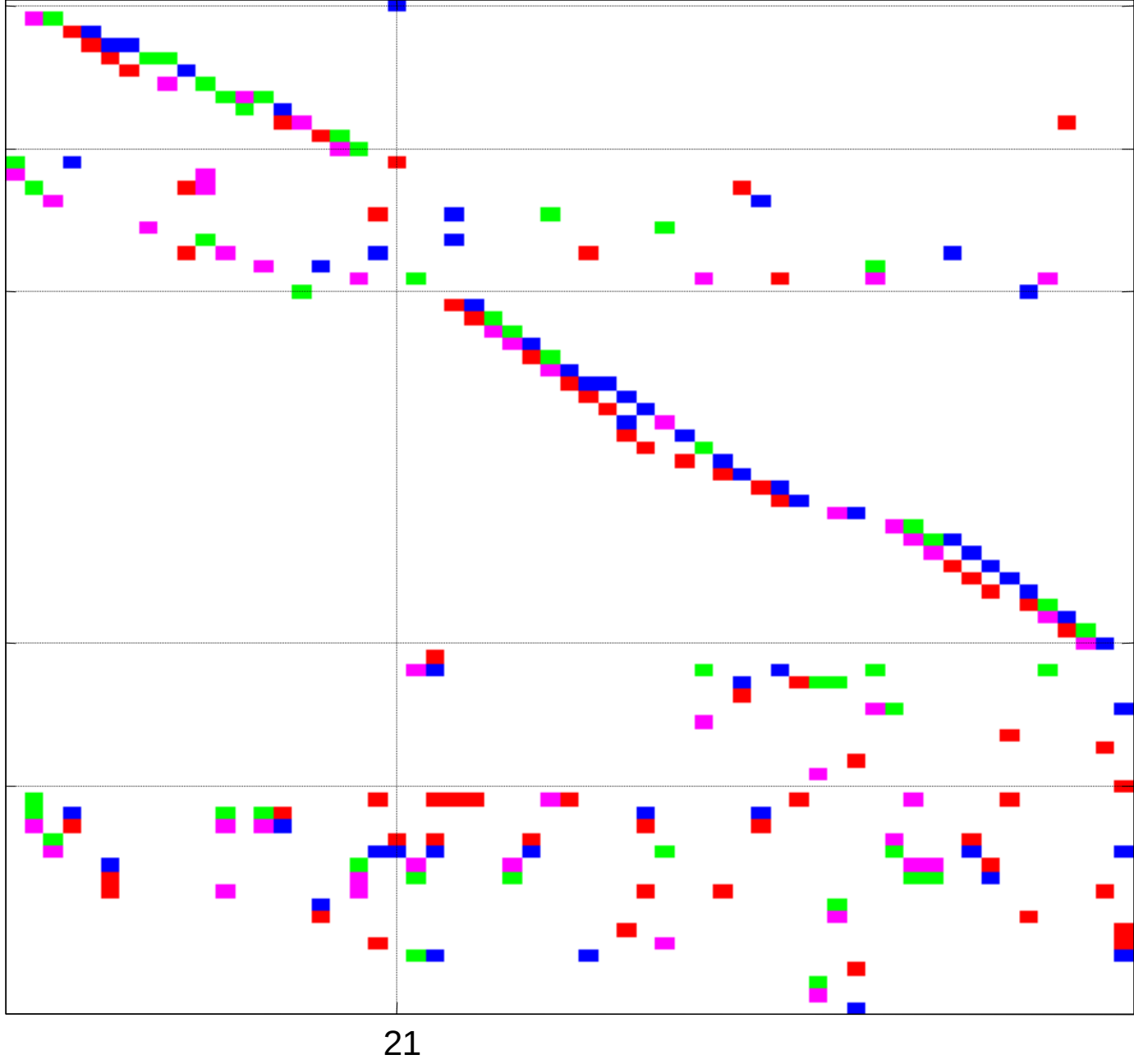
Vertes et al (2011) *Front Sys Neurosci*


H. Pylori Amino Acid Biosynthesis
GLC
G6P
PGL
PGC
RL5P
R5P
F6P
X5P
E4P
6PG
T3P
PEP
DPG
3PG
PYR
MAL
OA
CIT
FUM
SUC
SUCOA
ICIT
AKG
PRPP
AN
NAN
CD5
IGP
TRP
DAH
DQT
DHS
SME
S5P
PSM
CHO
PPN
HPP
TYR
CYS
ASE
PHP
PPS
SER
GLY
ASP
ASN
BAP
ASS
HSE
PHS
THR
DHD
PIP
SAK
SDP
DPI
MDP
LYS
GLN
GLU
PI
NAD
NADH
ADP
ATP
NADP
NADPH
CO2
COA
ACCOA
PPI
AMP
ATP
NH3
AC
THF
MTH
H2S



The carriers are a crucial element of modularity

Metabolism is trivially "small world" for water, energy, redox



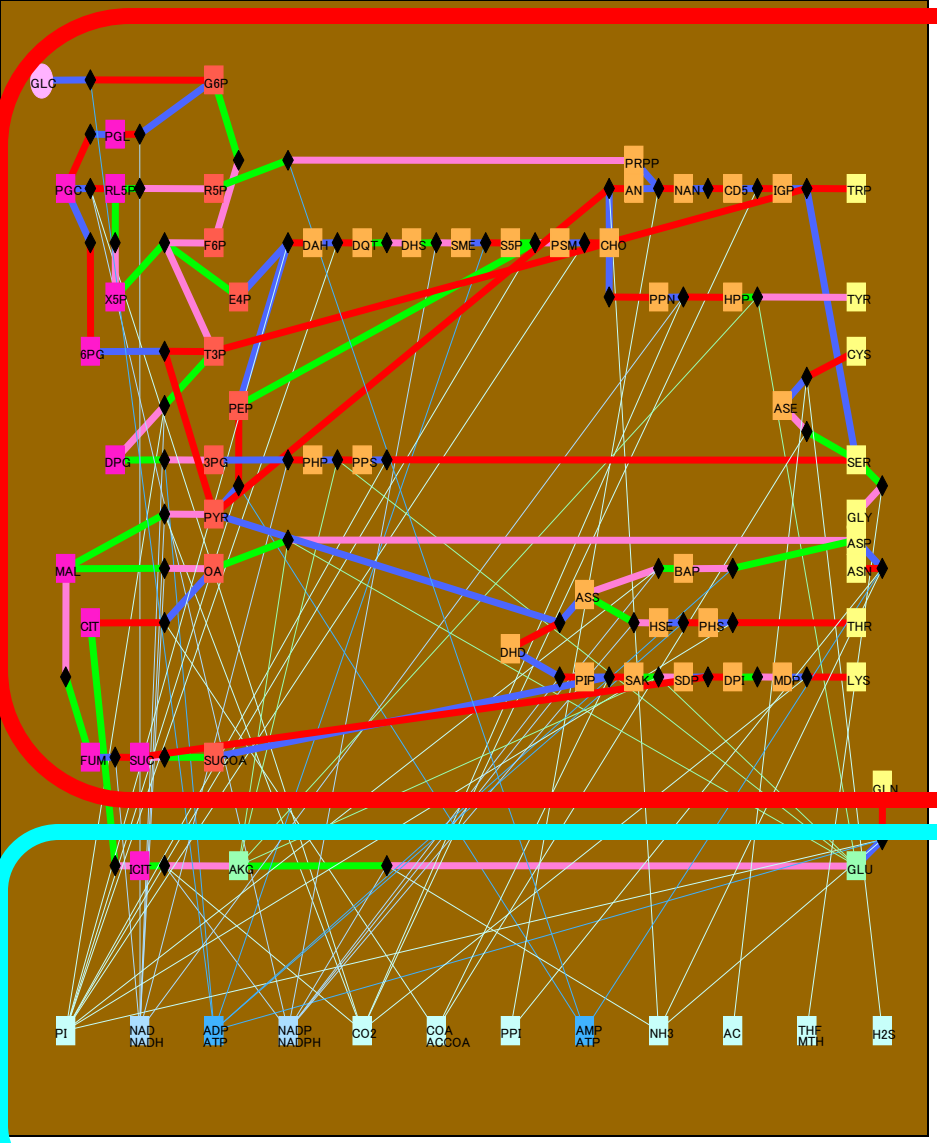
precursors

other metabolites

amino acids

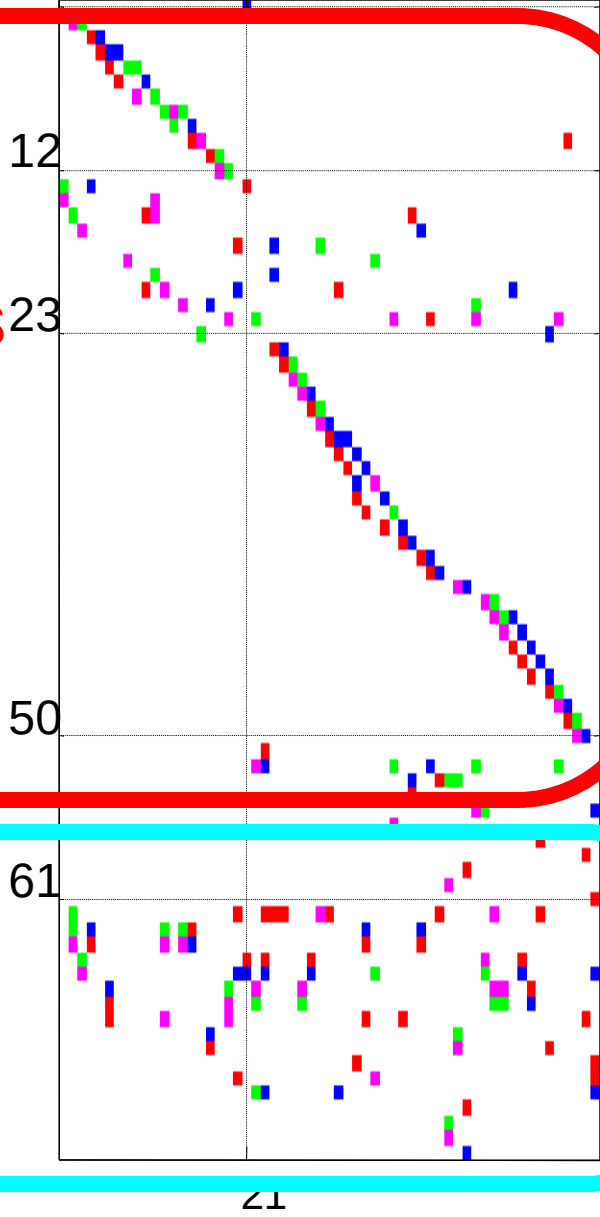
carriers

“Horizontal” decomposition



metabolites

carriers



reactions

“Vertical” decomposition

precursors 12

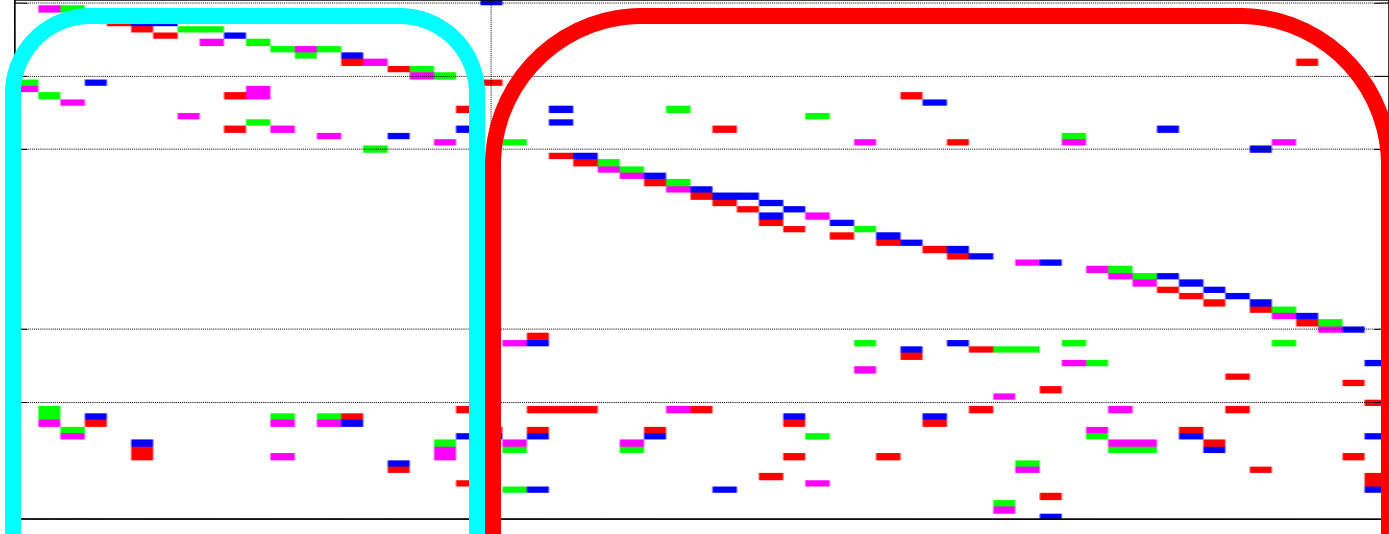
23

other metabolites

amino acids 50

61

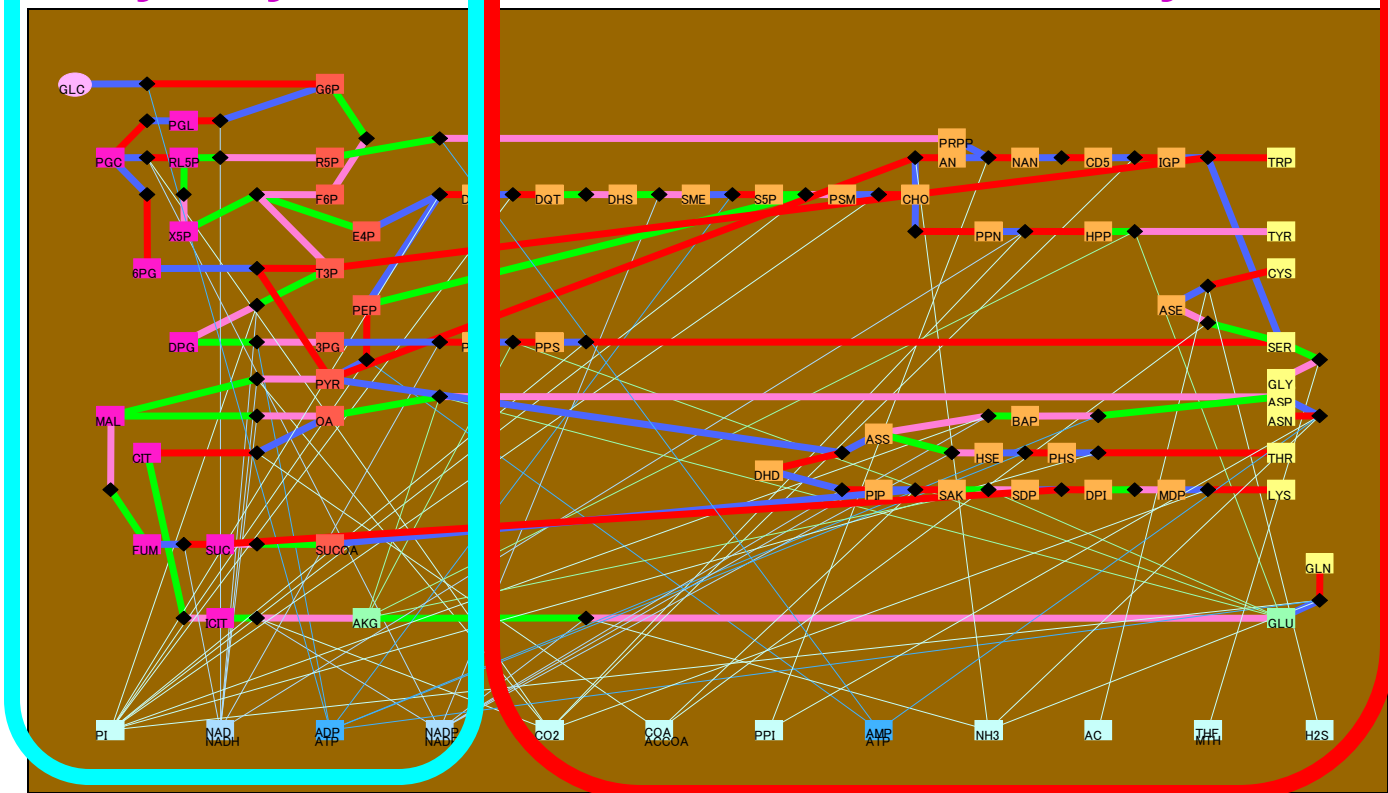
carriers



1

Glycolysis

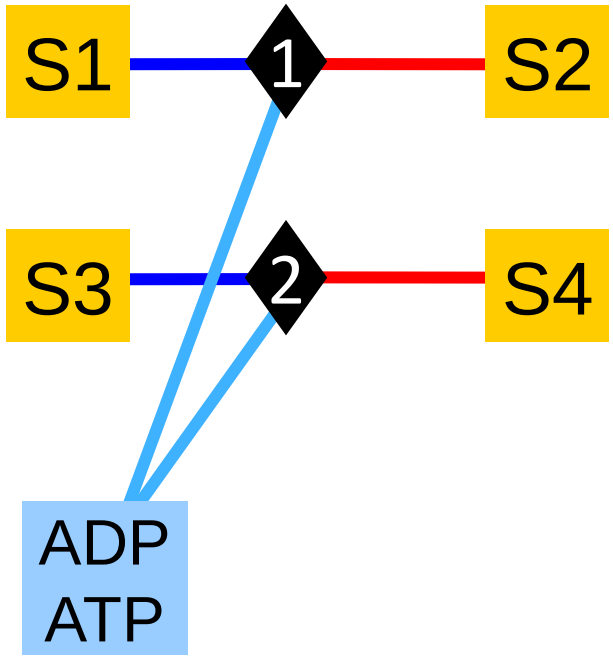
Amino Acid Biosyn



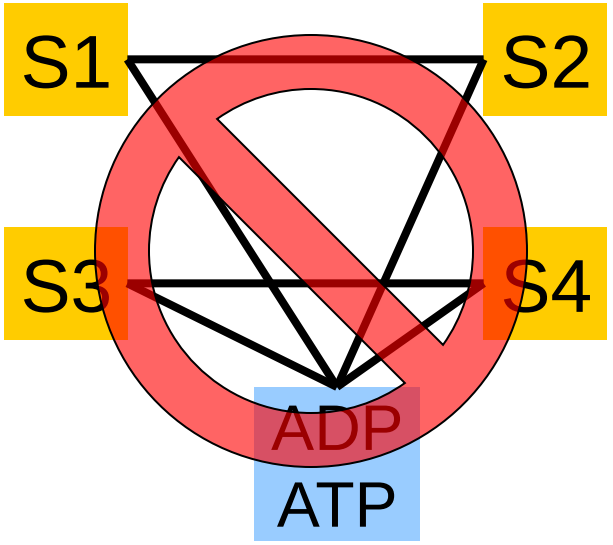
“Horizontal” decomposition

Unipartite projections lose too much.

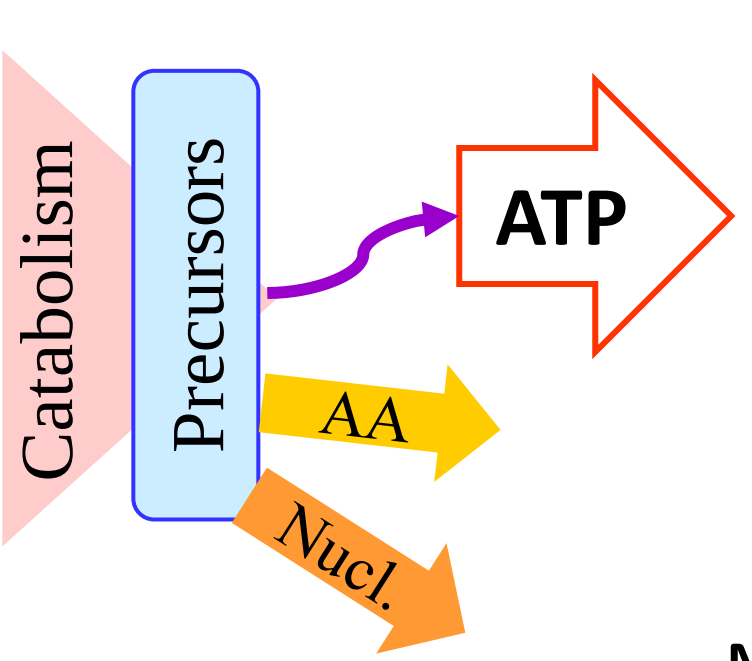
$$S_1 + ATP \rightarrow S_2 + ADP$$
$$S_3 + ATP \rightarrow S_4 + ADP$$

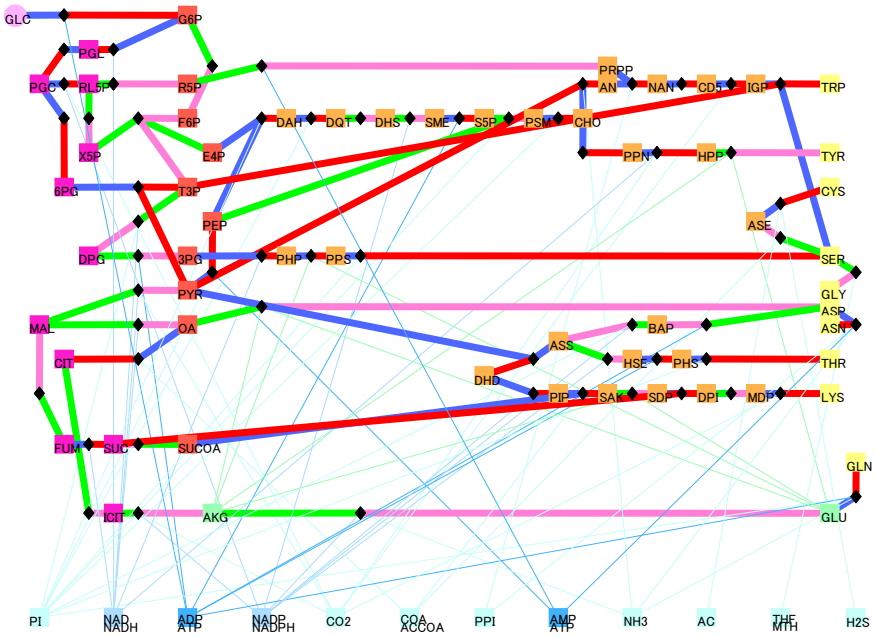


Substrate graph



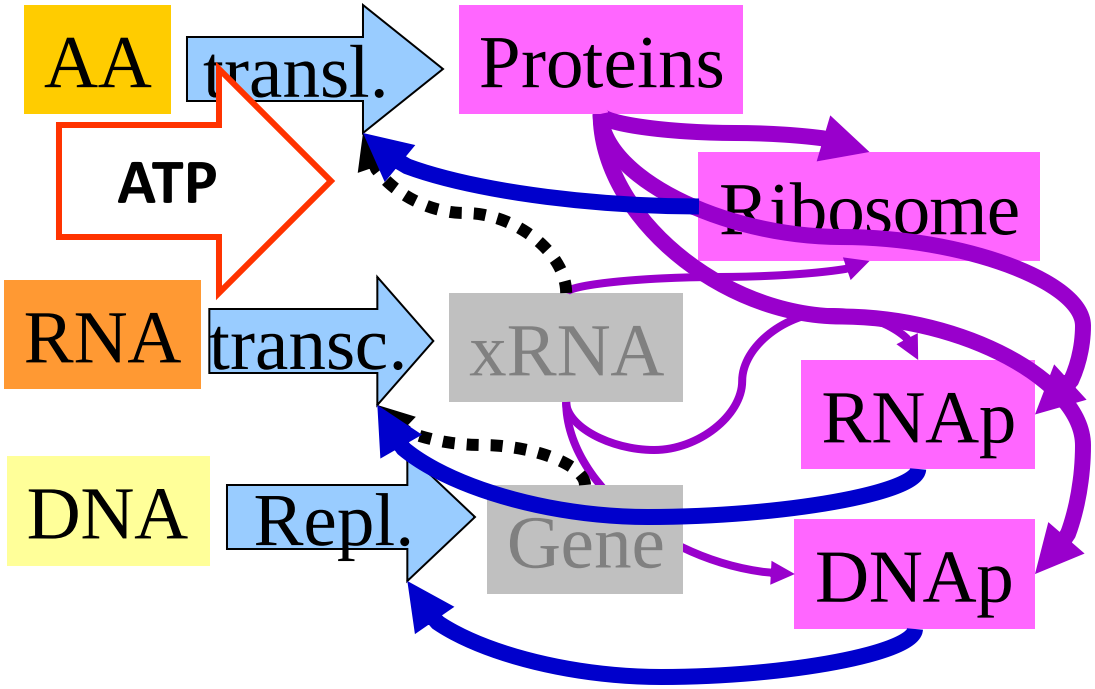
Reaction graph

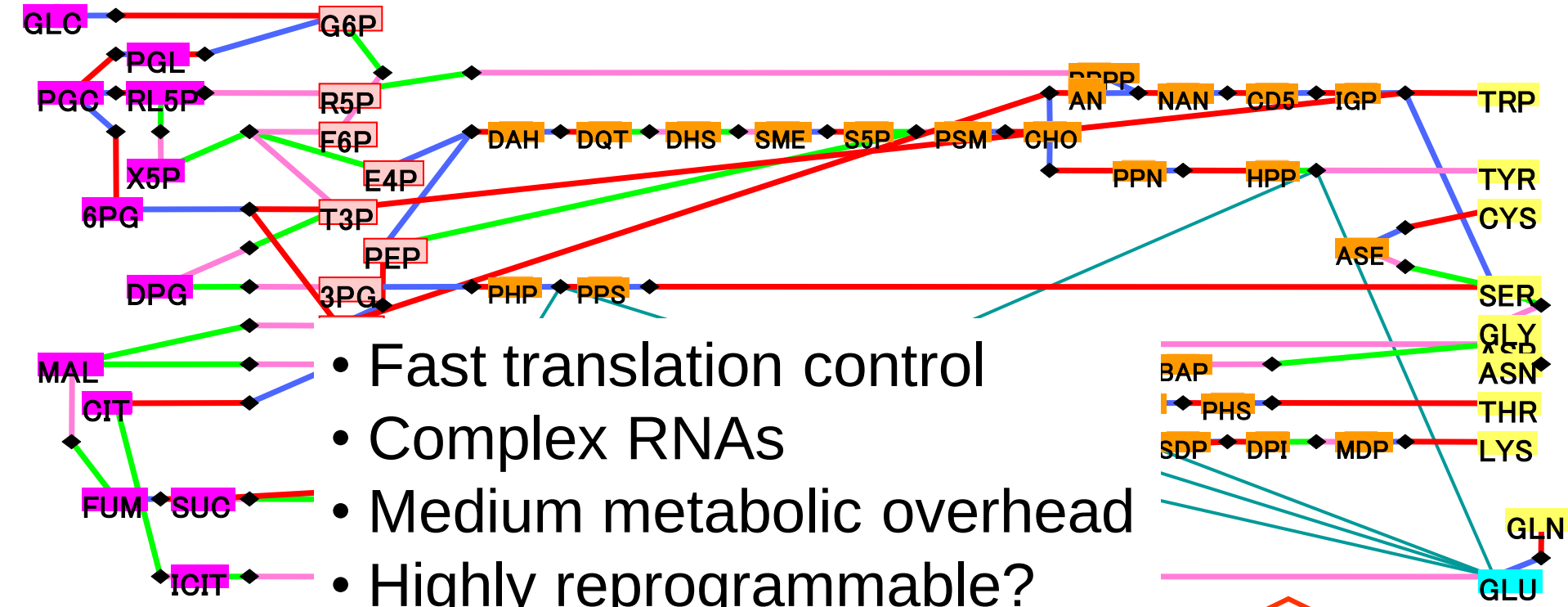




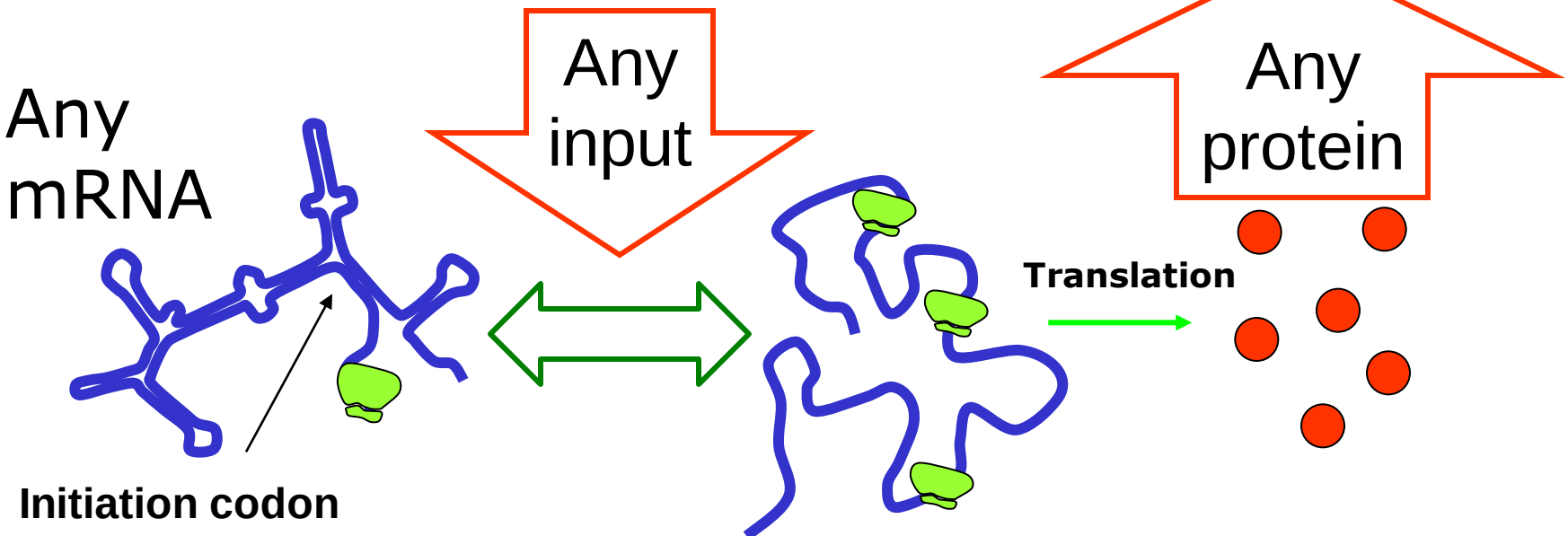
Macro-layers

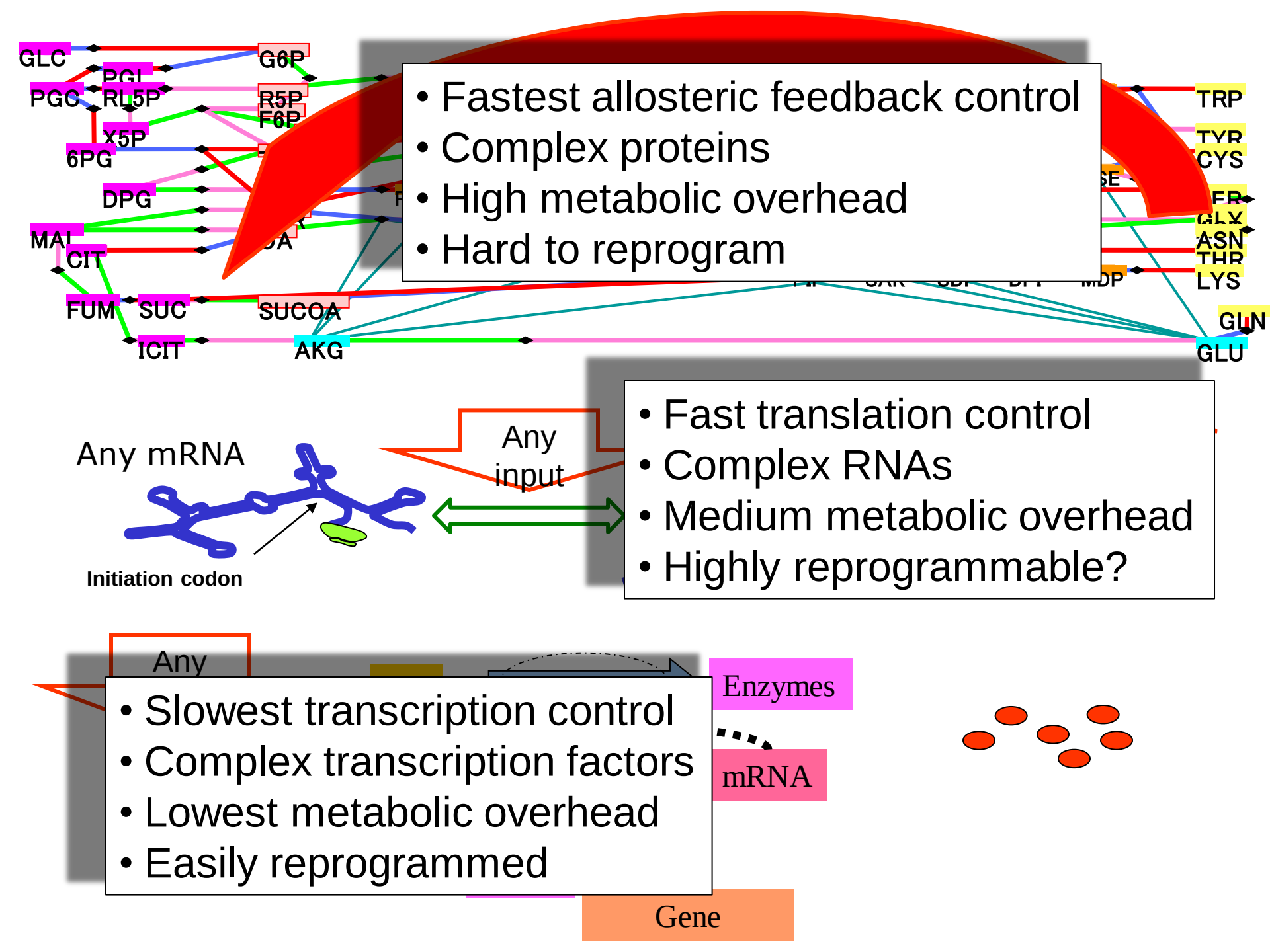
Other layers?

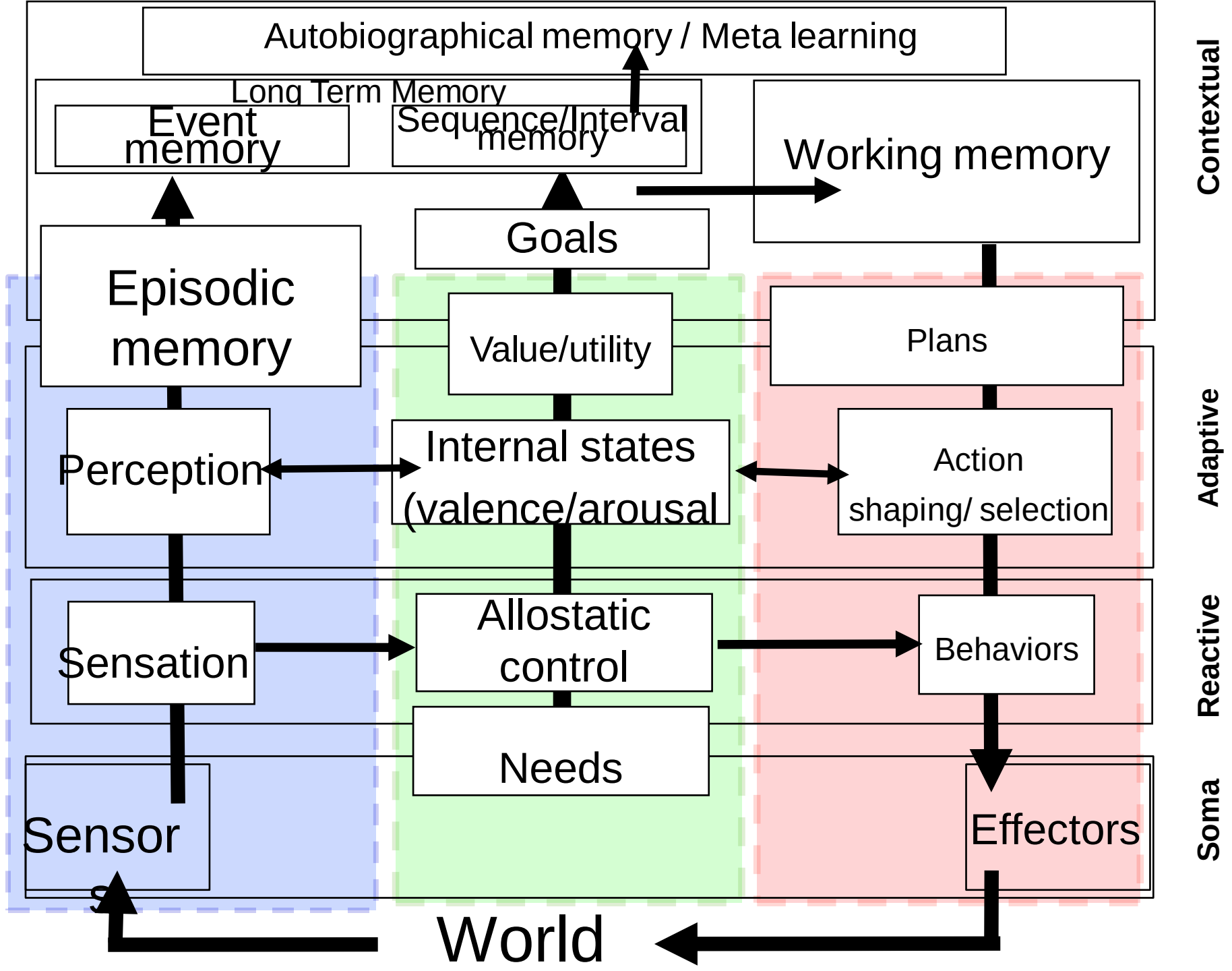




- Fast translation control
- Complex RNAs
- Medium metabolic overhead
- Highly reprogrammable?




GLC
G6P
PGC
R5P
F6P
X5P
6PG
DPG
CIT
FUM
SUC
SUCOA
ICIT
AKG
TRP
TYR
CYS
GLY
ASN
THR
LYS
GLN
GLU
• Fastest allosteric feedback control
• Complex proteins
• High metabolic overhead
• Hard to reprogram
Any mRNA
Initiation codon
Any input
• Fast translation control
• Complex RNAs
• Medium metabolic overhead
• Highly reprogrammable?
Any
• Slowest transcription control
• Complex transcription factors
• Lowest metabolic overhead
• Easily reprogrammed
Enzymes
mRNA
Gene


Autobiographical memory / Meta learning
Long Term Memory
Event memory
Sequence/Interval memory
Working memory
Goals
Episodic memory
Value/utility
Plans
Perception
Internal states (valence/arousal
Action shaping/ selection
Sensation
Allostatic control
Behaviors
Needs
Sensor s
Effectors
World
Contextual
Adaptive
Reactive
Soma