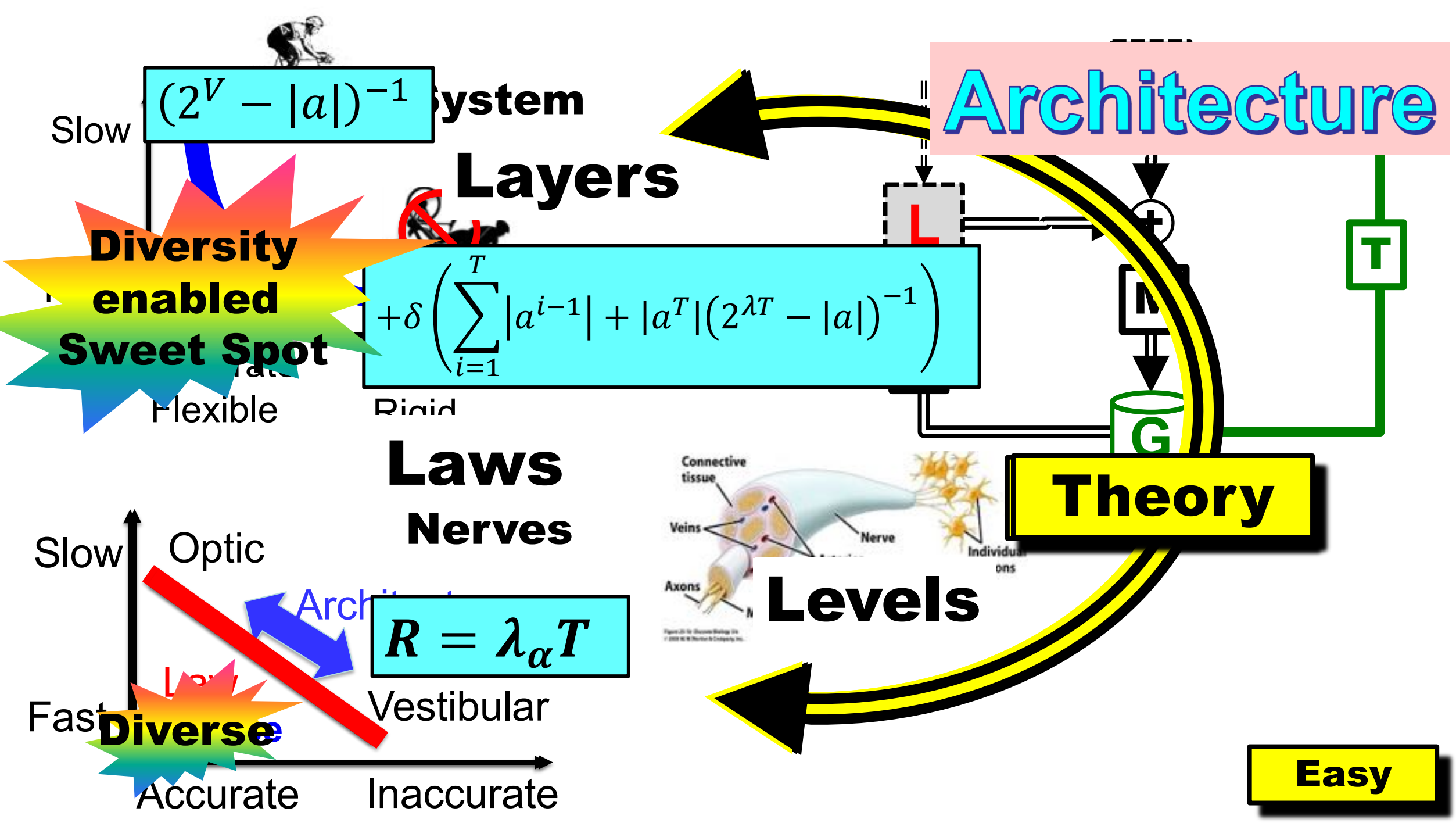
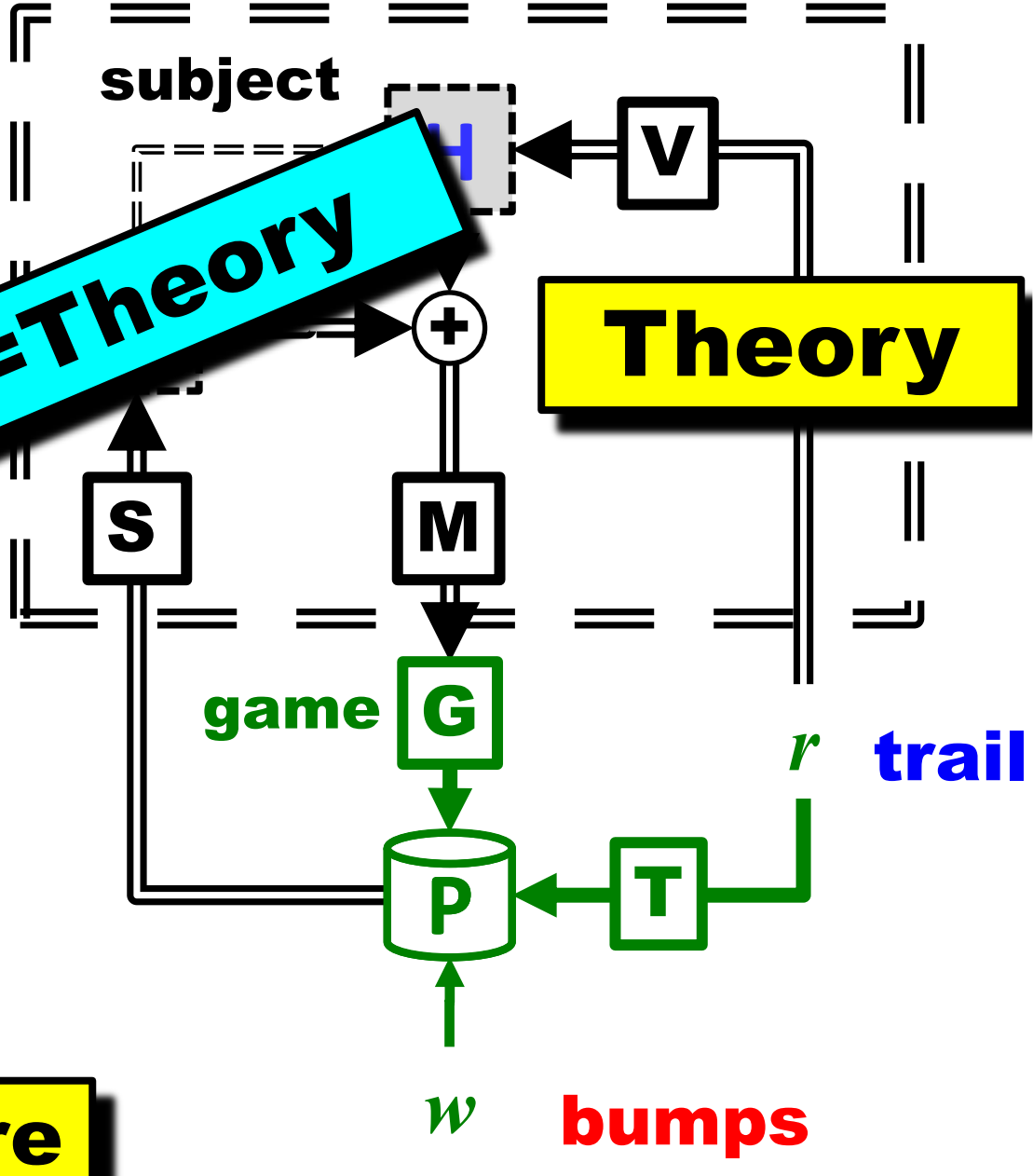

$(2^V - |a|)^{-1}$
Slow
ystem
Layers
Diversity enabled Sweet Spot
$+\delta\left(\sum_{i=1}^{T}|a^{i-1}| + |a^T|(2^{\lambda T} - |a|)^{-1}\right)$
Flexible
Rigid
L
N
T
G
Architecture
Theory
Laws
Nerves
Connective tissue
Veins
Nerve
Axons
Levels
Slow
Optic
Fast
Vestibular
Accurate
Inaccurate
$R = \lambda_\alpha T$
Diverse
Easy

Function

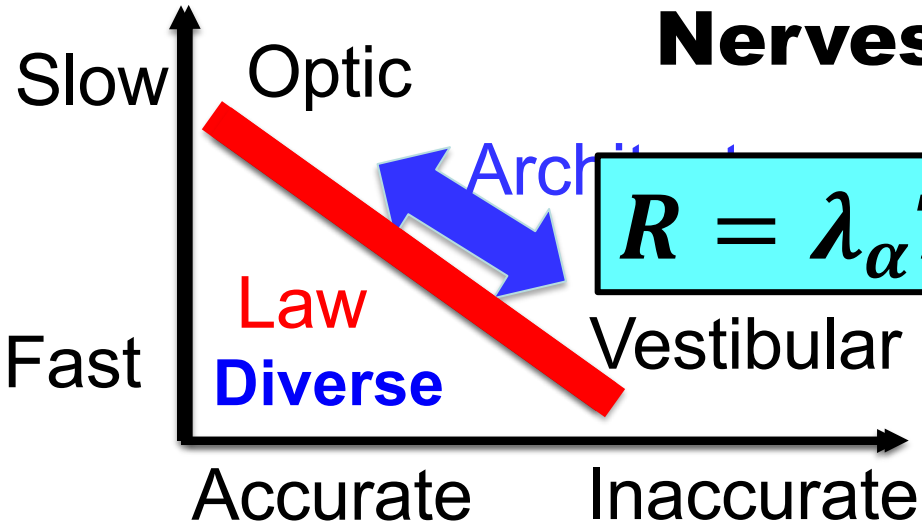
Bumps

Levels

Data=Theory



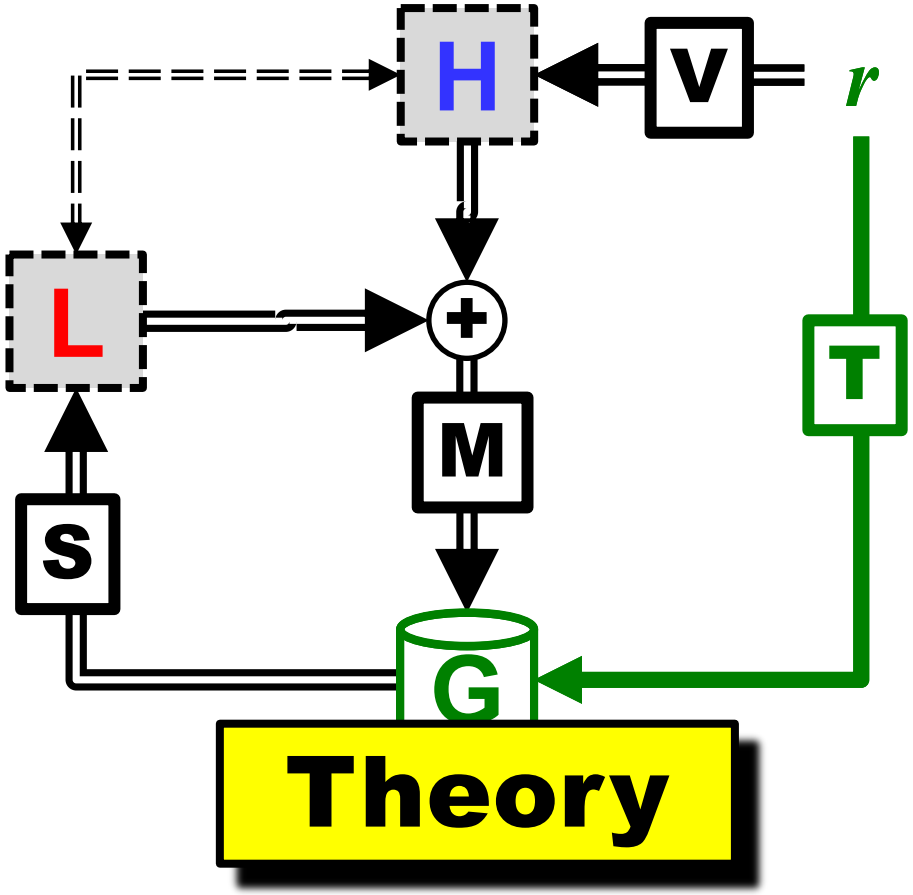
Nerves



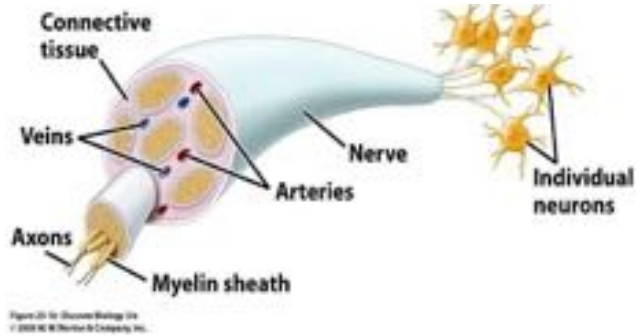
$$R = \lambda_{\alpha} T$$

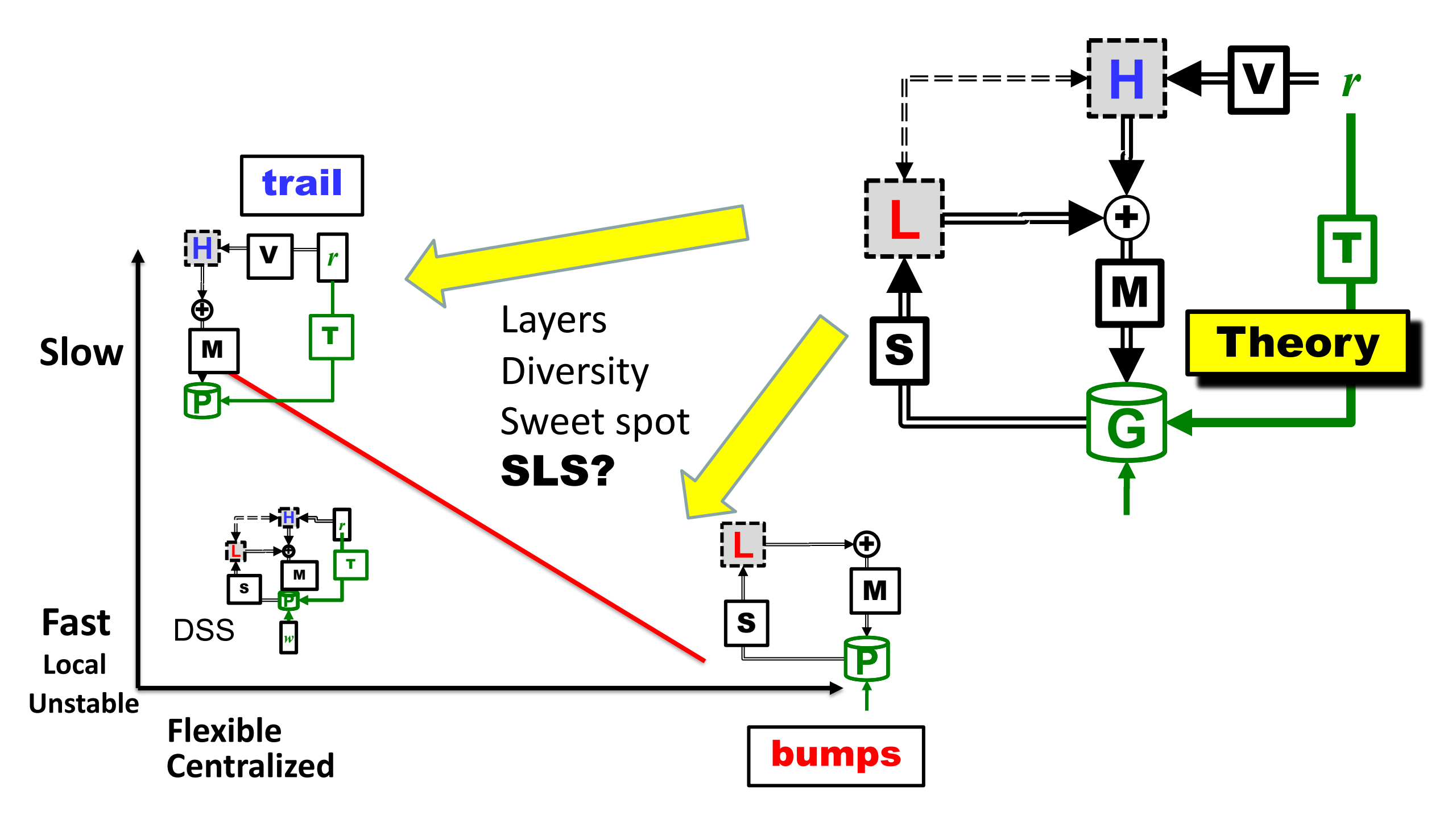
Hardware

- Scalar trail and bumps
- Math is easy
- (Experiments are easy)
- **Has no additional *internal* structure (e.g. within cortex)**
- Beyond what is in the diagram
- What next?



- **1 dimensional**
- **scalar trail**
- **scaler bump**




trail
H
V
r
M
T
P
Slow
Layers
Diversity
Sweet spot
SLS?
L
S
M
T
Theory
G
DSS
Fast
Local
Unstable
Flexible
Centralized
bumps

Trail

Layers

Accurate

System *level*

Fast

Diverse

Fast

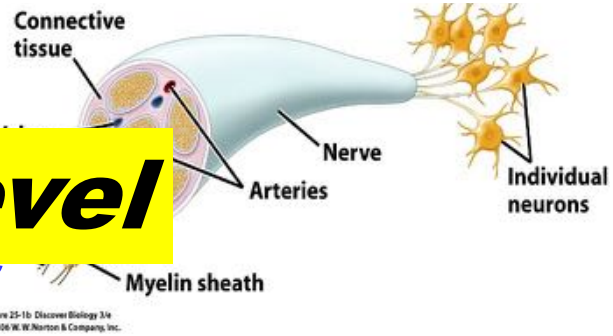
Bumps

Accurate

Flexible

Inaccurate

Rigid



Slow

Opti

Nerve *level*

Law

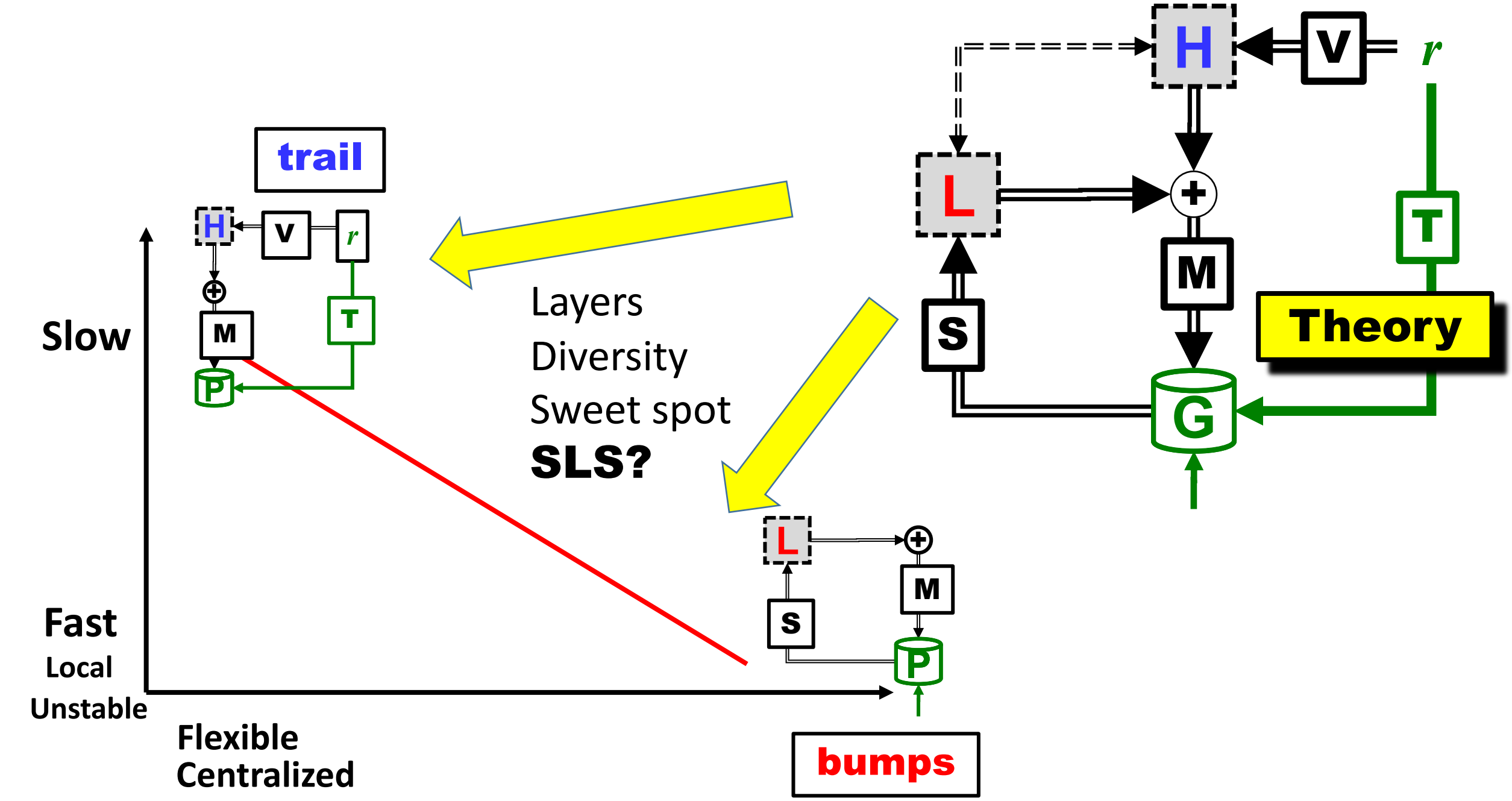
Fast

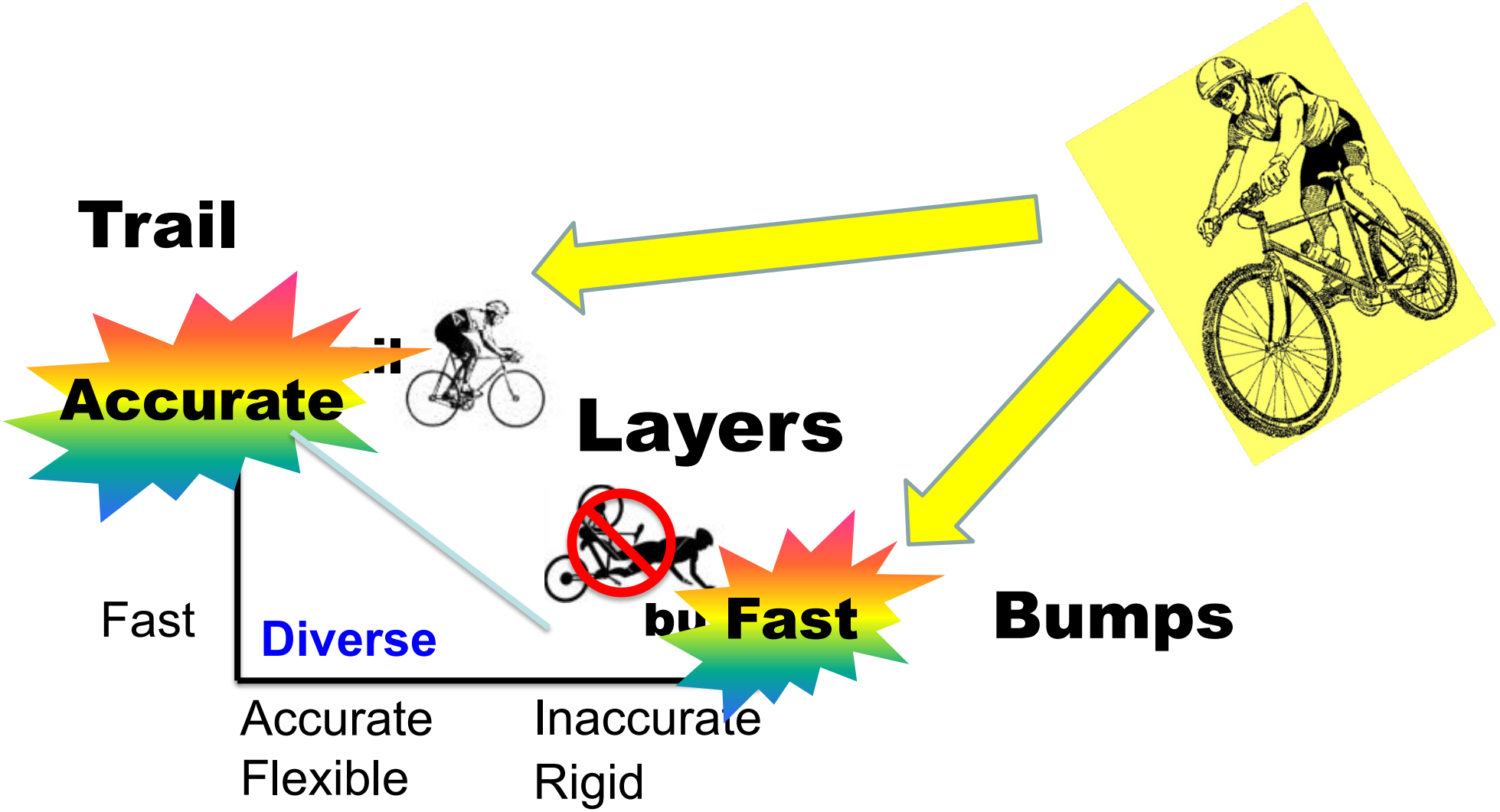
Diverse

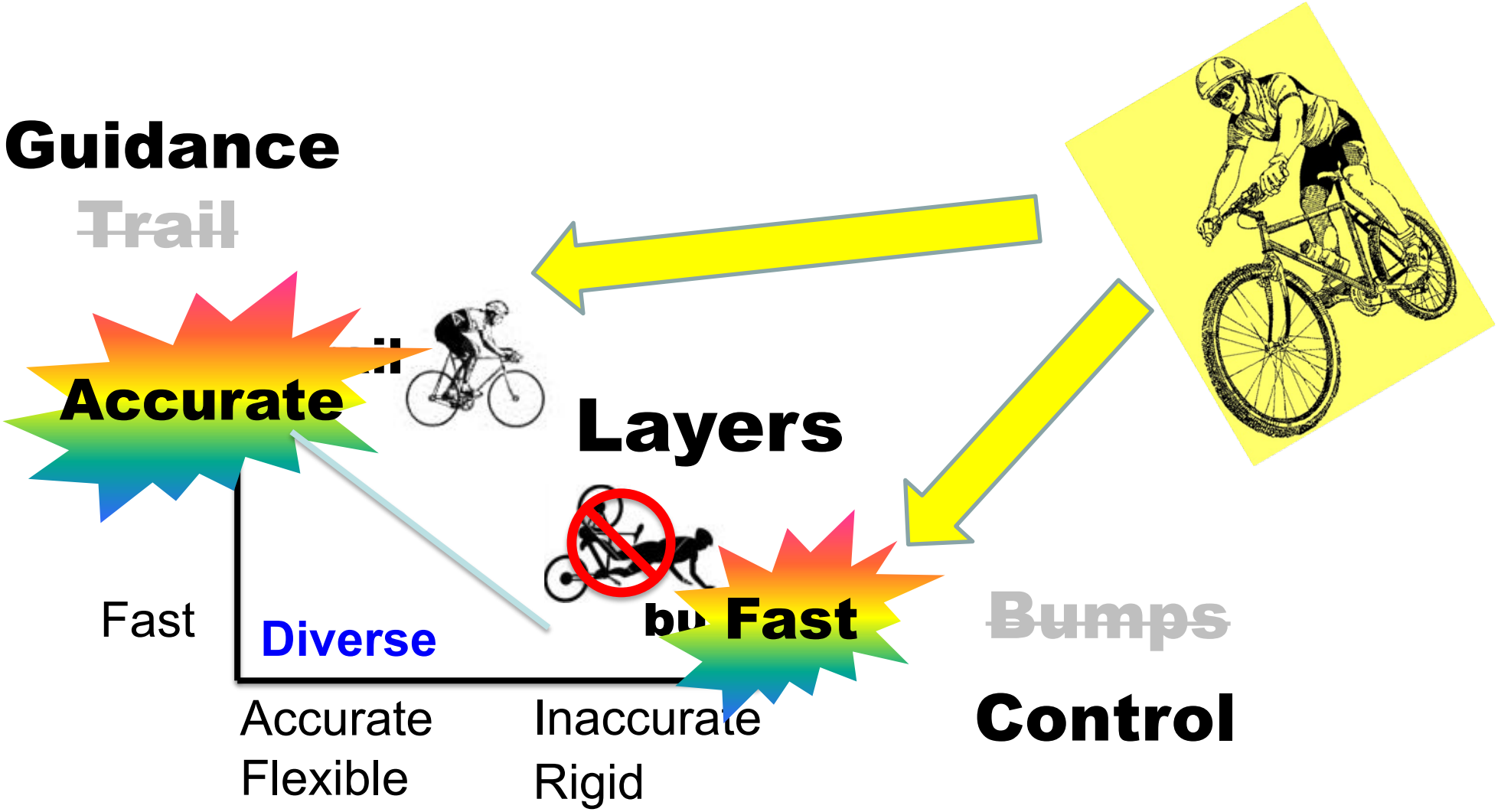
Vestibular

Accurate

Inaccurate


trail
H
V
r
M
T
P
Slow
Fast
Local
Unstable
Flexible
Centralized
Layers
Diversity
Sweet spot
SLS?
L
S
bumps
Theory
G


Trail
Accurate
Layers
Fast
Diverse
Fast
Bumps
Accurate
Flexible
Inaccurate
Rigid


Guidance
Trail
Accurate
Layers
Fast
Diverse
Fast
Bumps
Accurate
Flexible
Inaccurate
Rigid
Control

Navigation

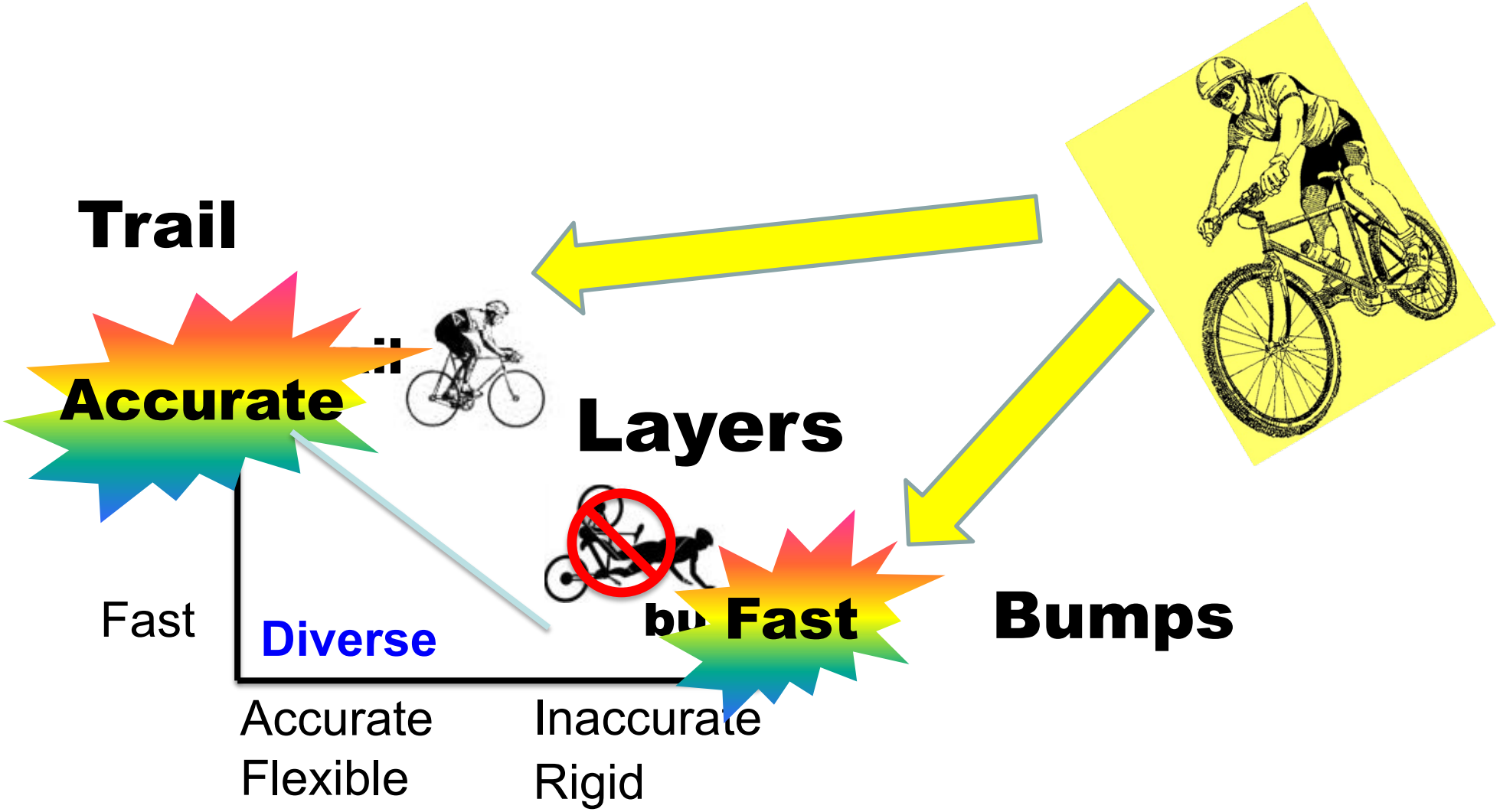
Guidance

~~Trail~~

Fast

~~Bumps~~

Control


Trail
Accurate
Layers
Fast
Diverse
Fast
Bumps
Accurate
Flexible
Inaccurate
Rigid

Trail

Accurate

Layers

System *level*

Fast

Diverse

Fast

Bumps

Accurate
Flexible

Inaccurate
Rigid

Trail

Layers

Accurate

System *level*

Fast

Diverse

Fast

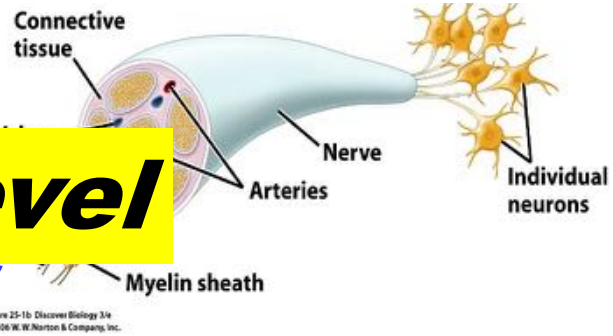
Bumps

Accurate

Flexible

Inaccurate

Rigid



Slow

Opti

Nerve *level*

Law

Fast

Diverse

Vestibular

Accurate

Inaccurate

Trail

Accurate

Layers

System level

Fast

Diverse

Accurate
Flexible

Inaccurate
Rigid

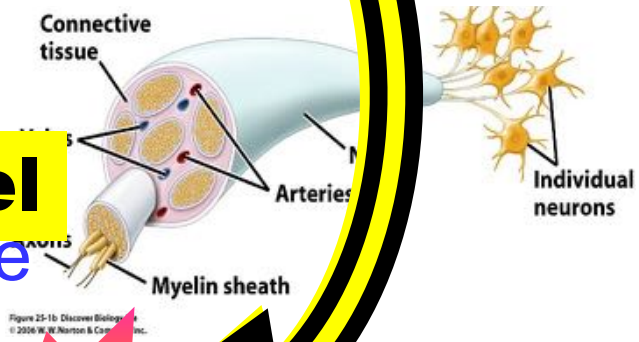
Fast

Bumps

Accurate

Nerve level

Architecture



Law

Fast

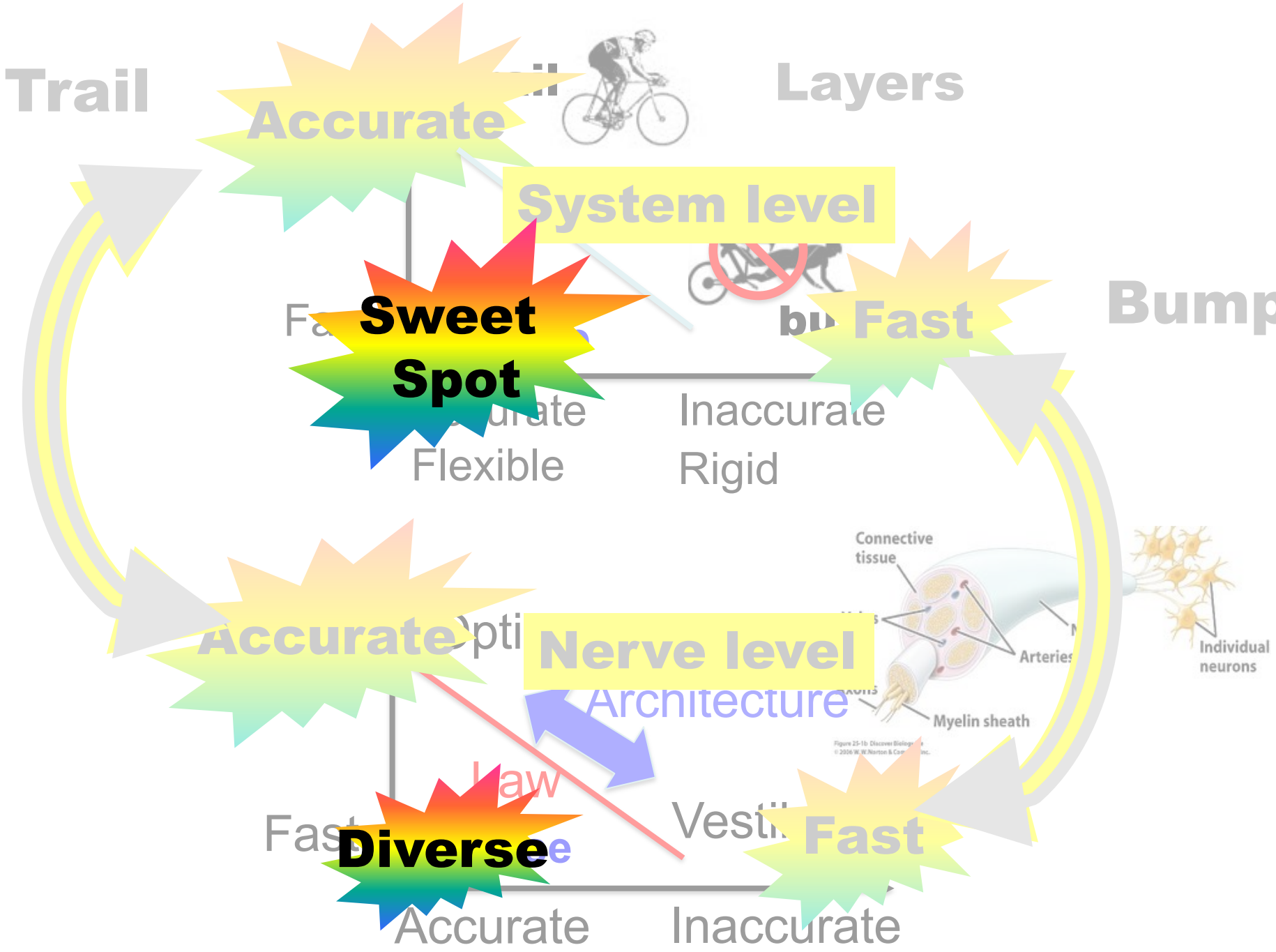
Diverse

Accurate

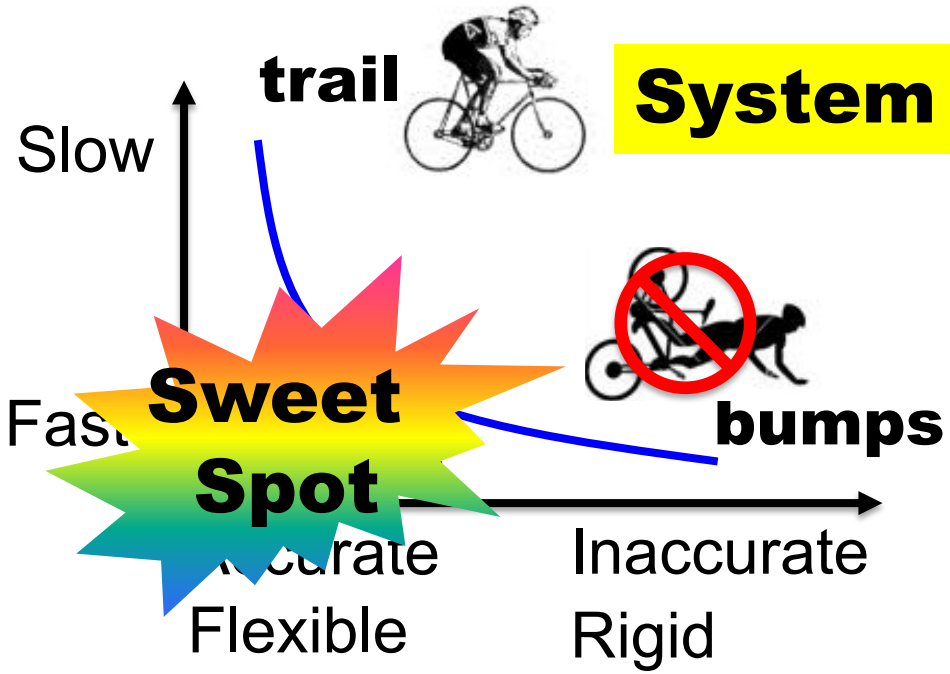
Inaccurate

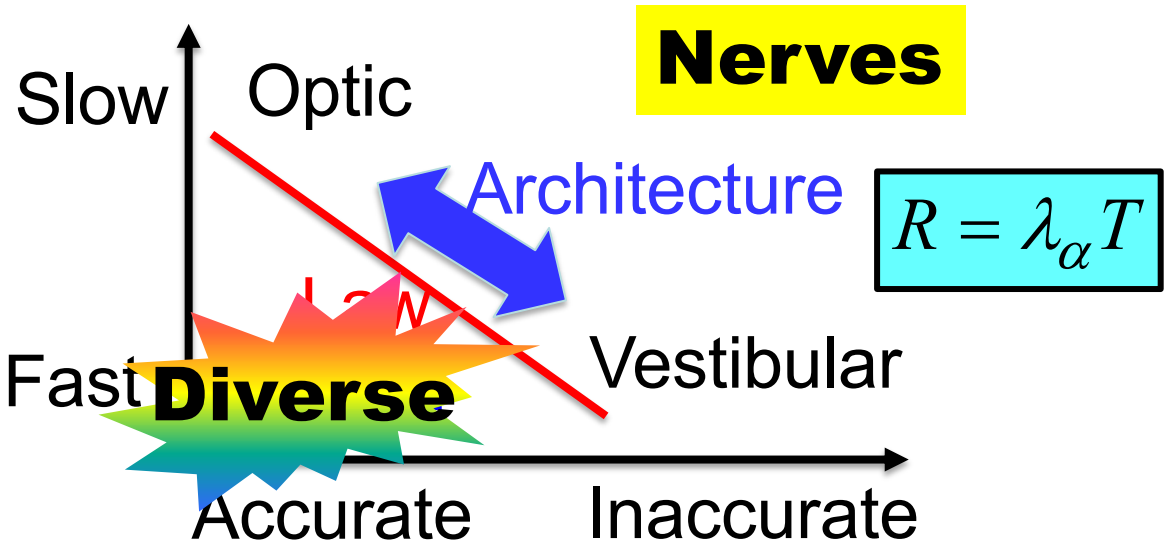
Fast

- Simple map across levels
- Special, convenient case



- Simple map across levels
- Special, convenient case

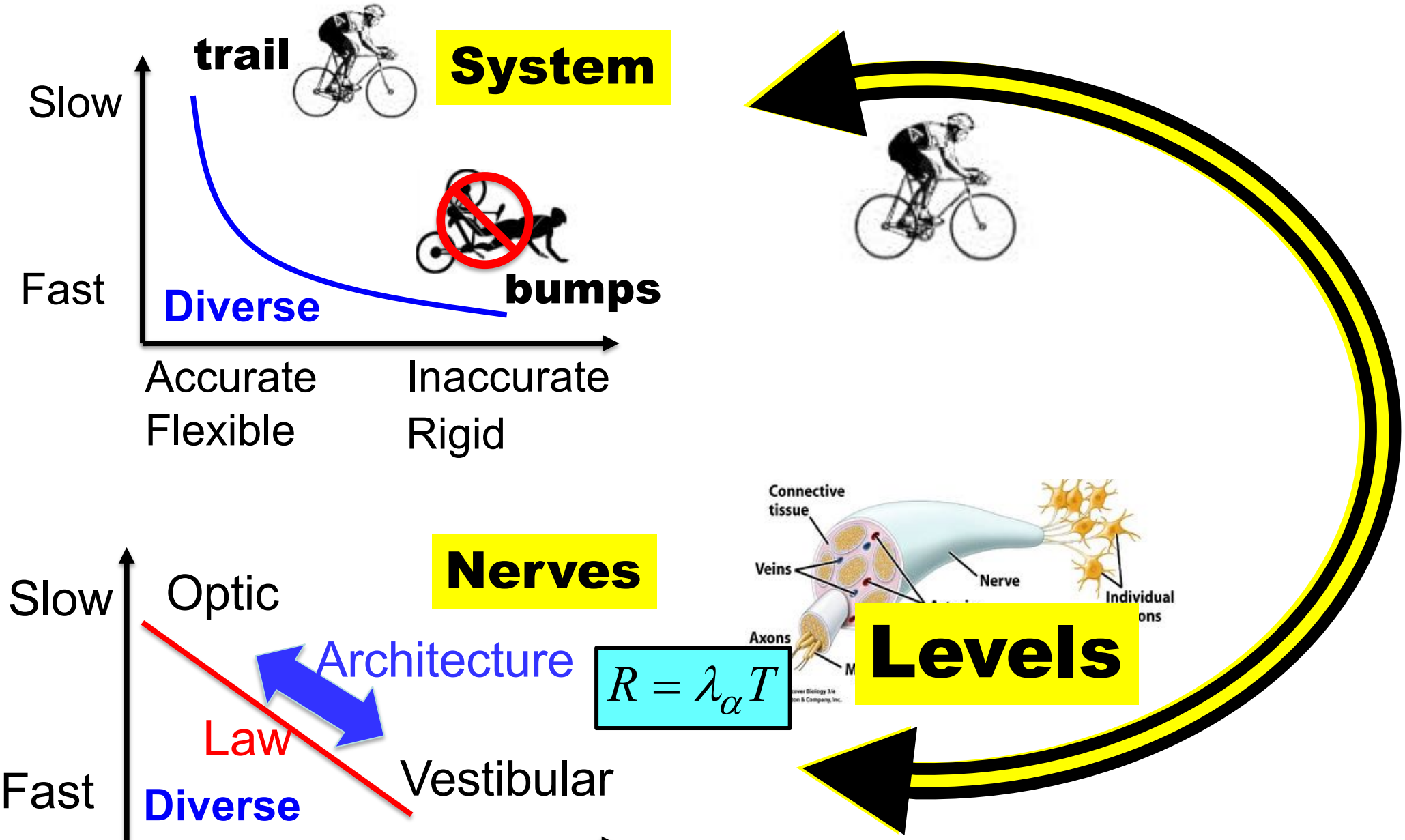




Diversity enabled sweet spot

- The point of architecture
- Combines diverse layers and levels
- To create functionality that no component alone can achieve

- **Diversity crosses levels and layers**


trail
System
Slow
Fast
Diverse
bumps
Accurate
Inaccurate
Flexible
Rigid
Nerves
Slow
Optic
Architecture
Law
Fast
Diverse
Vestibular
Accurate
Inaccurate
Connective tissue
Veins
Nerve
Individual
Axons
$R = \lambda_\alpha T$
Levels

trail

System

Slow

Fast

Diverse

bumps

Accurate

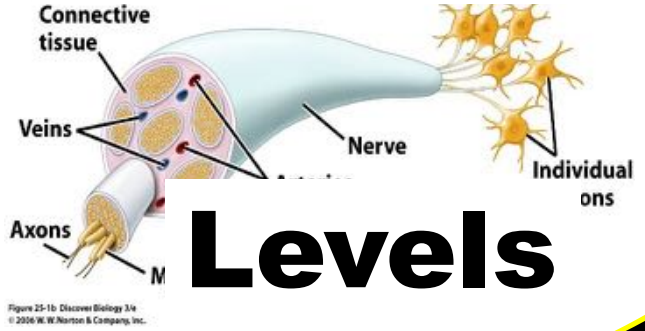
Inaccurate

Flexible

R **Laws**

What is possible.

Every layer and level has its own laws.



Levels

Nerves

Slow

Optic

Archit

$$R = \lambda_\alpha T$$

Law

Fast

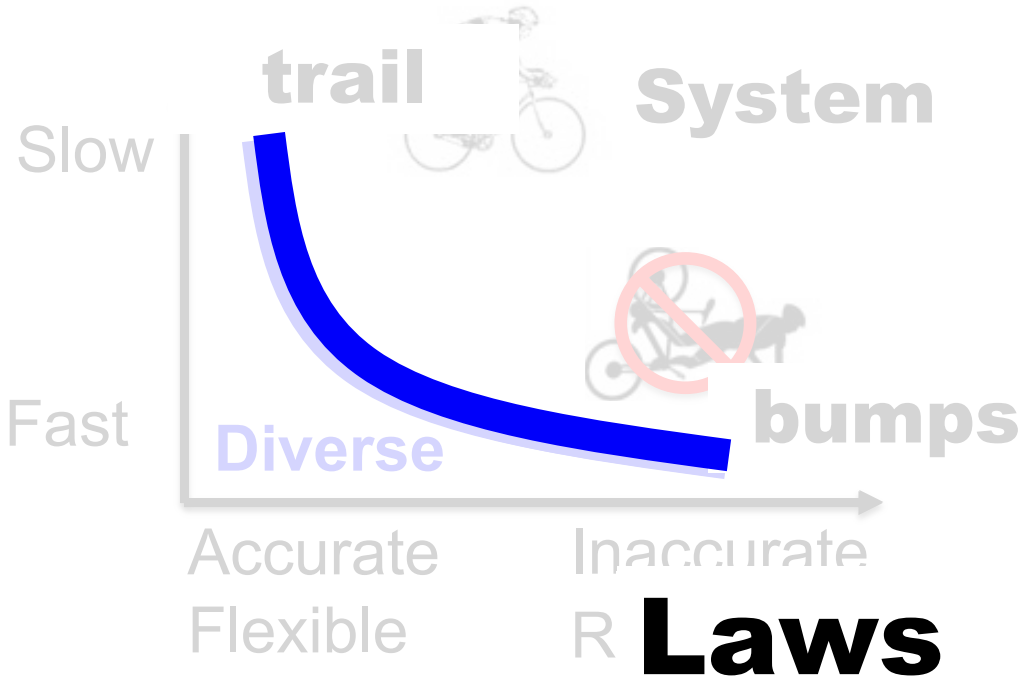
Diverse

Vestibular

Accurate

Inaccurate

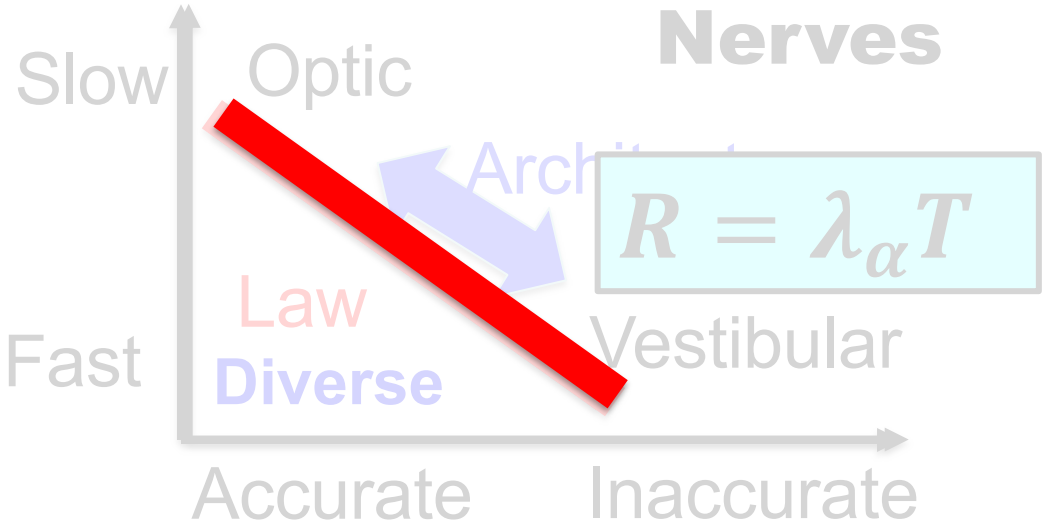
What is possible.



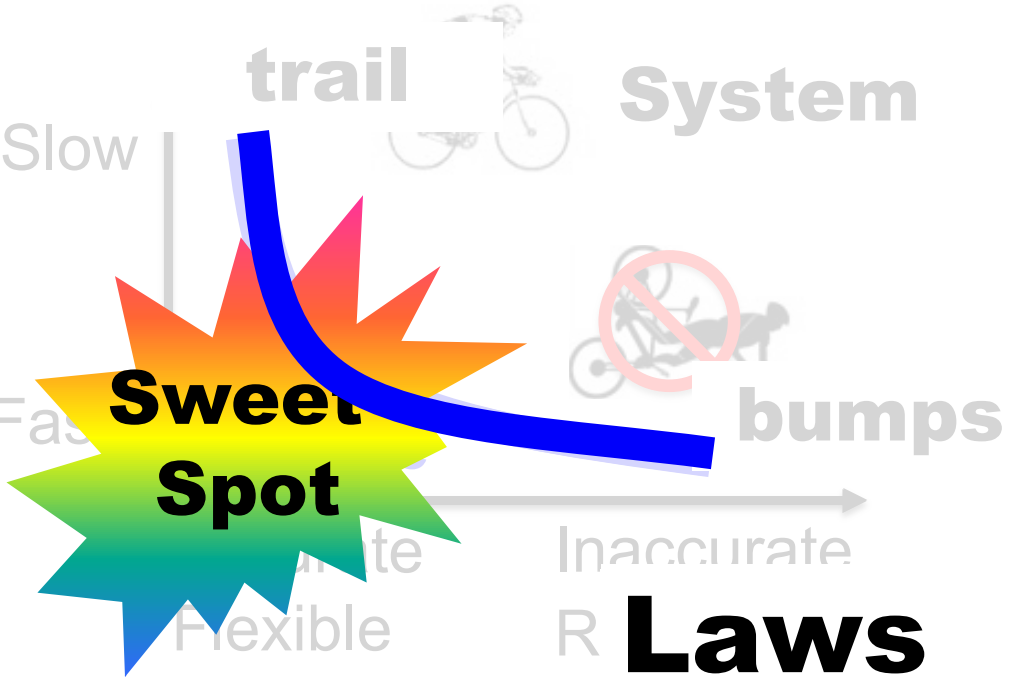
Laws

Every layer and level has its own laws.

Levels

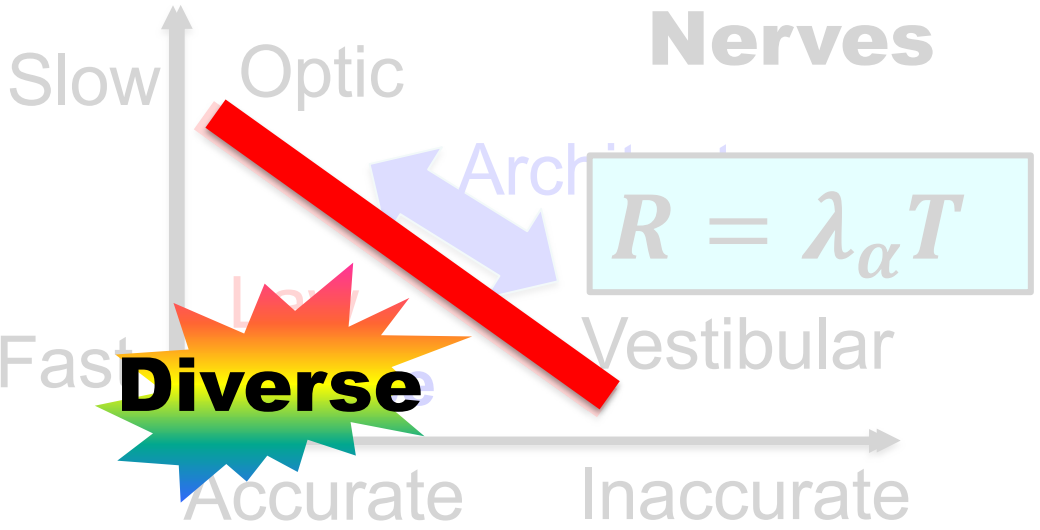


What is possible.

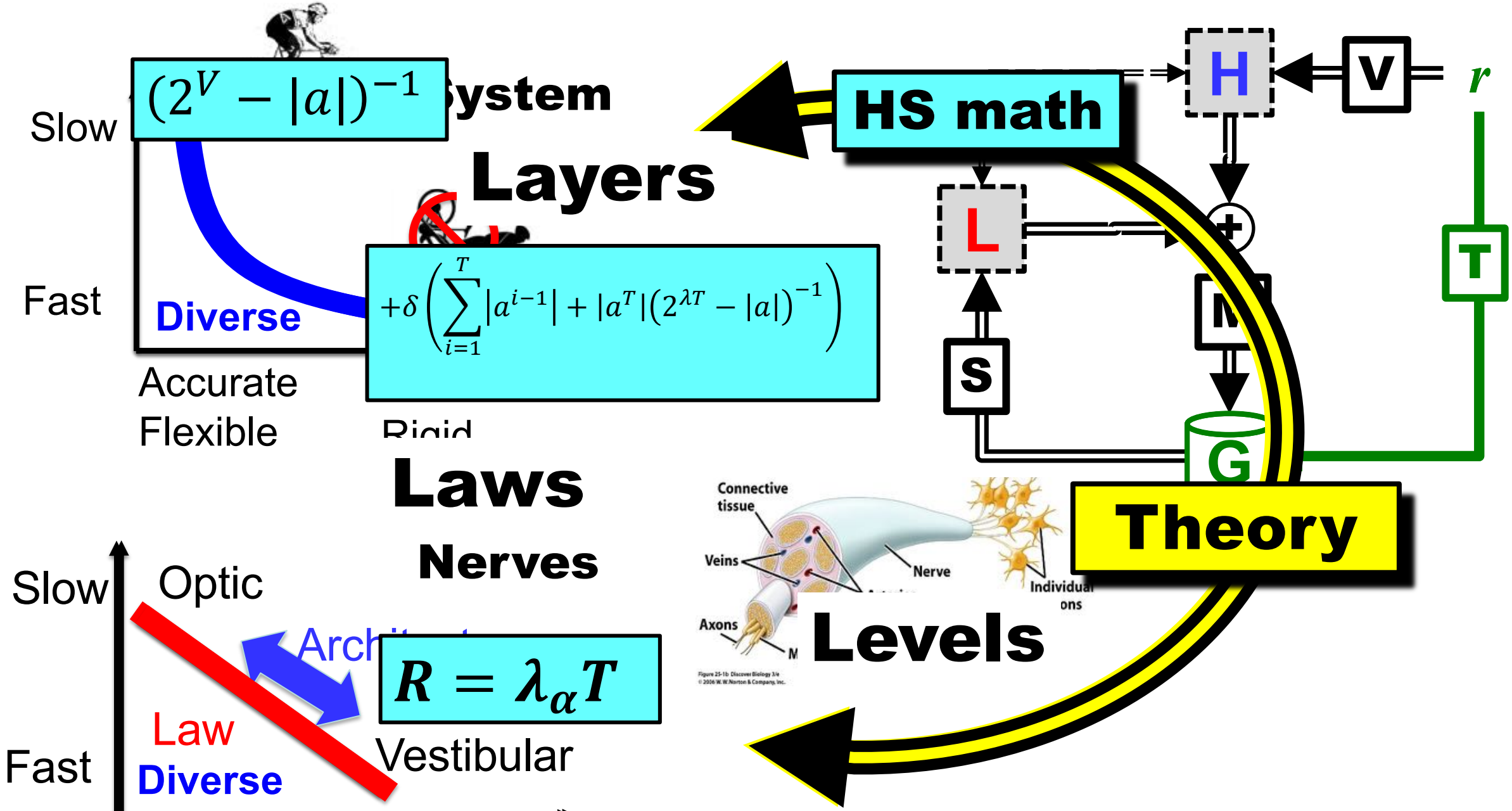


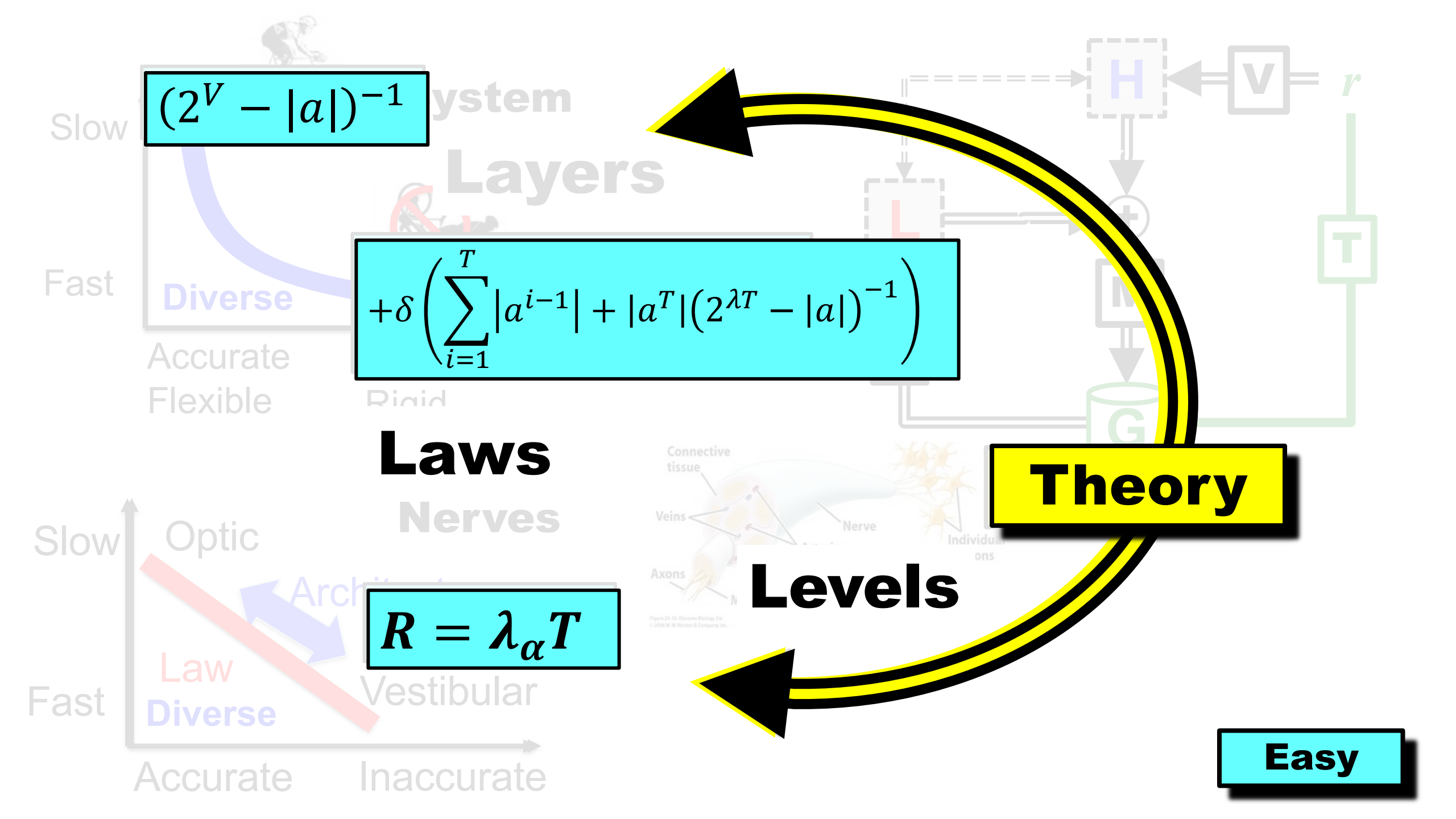
Laws

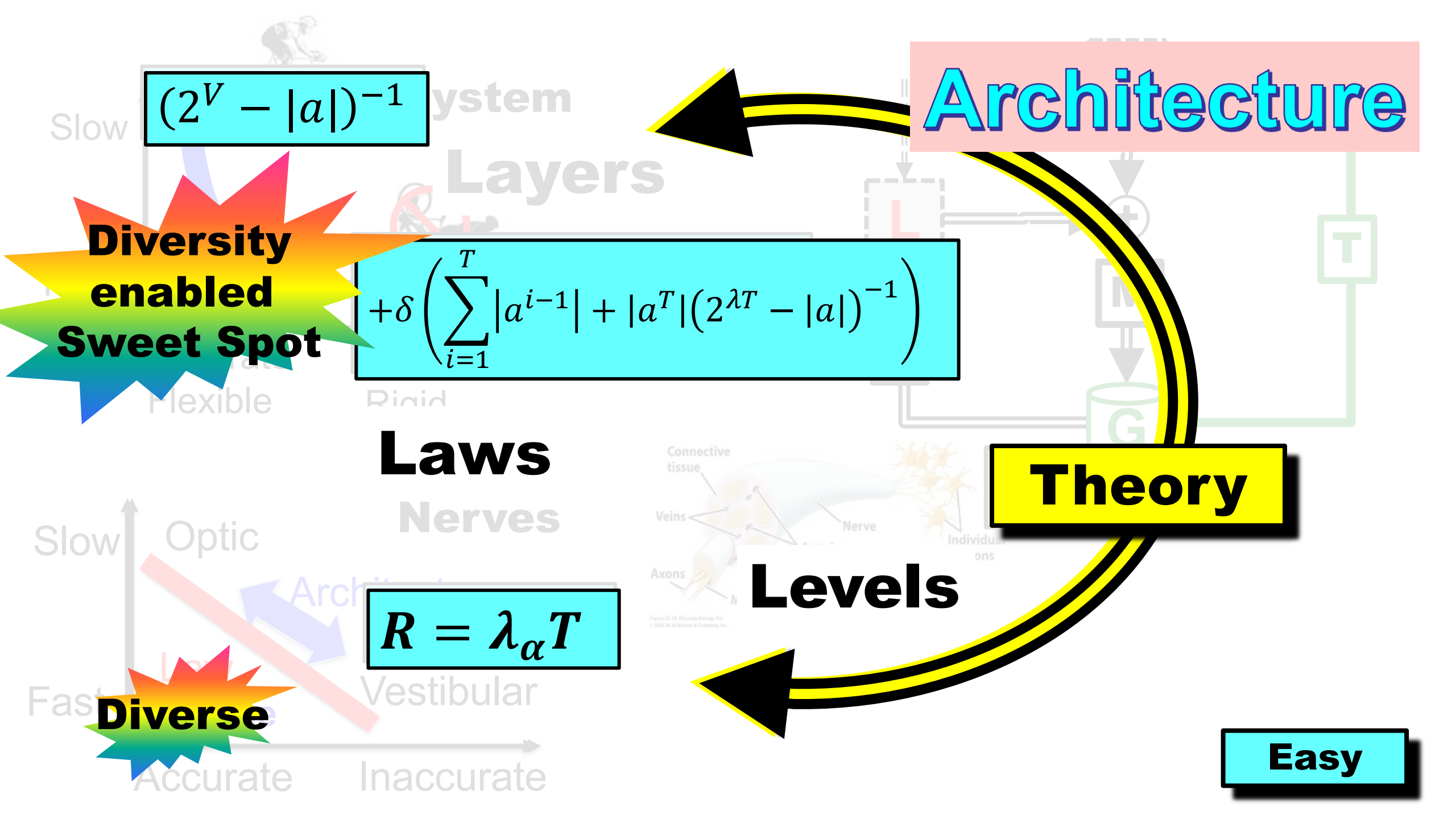
(only) architecture can create sweet spots.

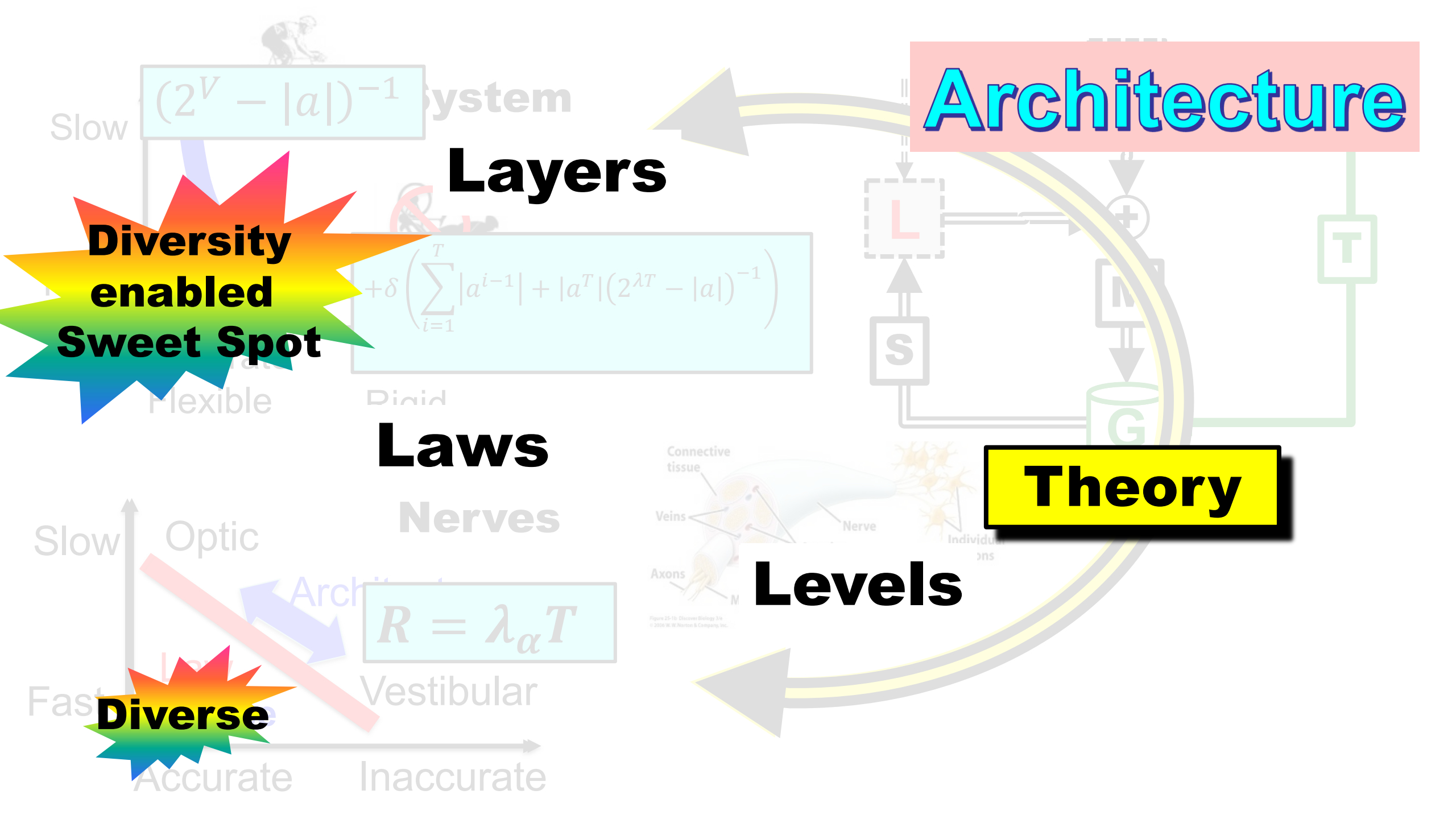


$$R = \lambda_{\alpha} T$$

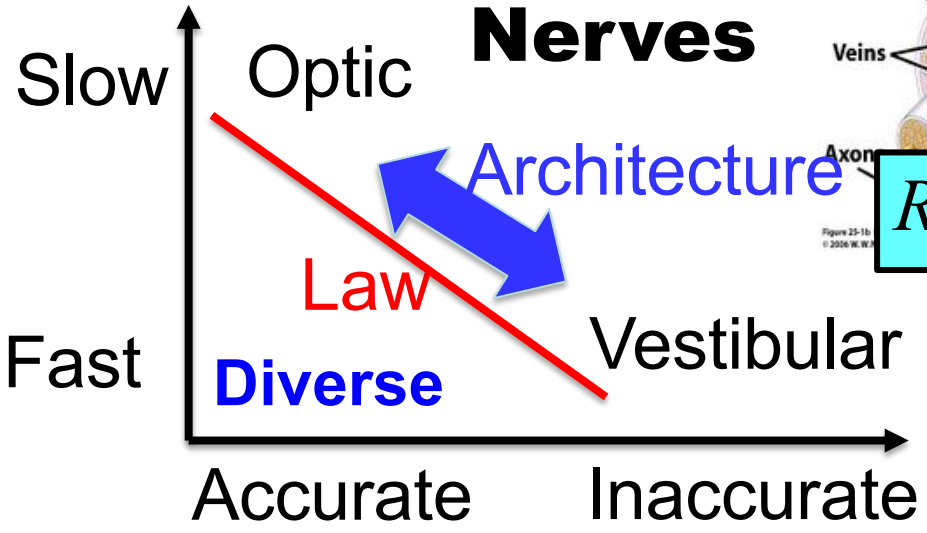

Slow
$(2^V - |a|)^{-1}$
ystem
Layers
Fast
Diverse
Accurate
Flexible
$+\delta\left(\sum_{i=1}^{T}|a^{i-1}| + |a^T|(2^{\lambda T} - |a|)^{-1}\right)$
Rigid
HS math
H
V
r
L
T
S
N
G
Theory
Laws
Nerves
Connective tissue
Veins
Nerve
Axons
Levels
Slow
Optic
Archit
Law
Diverse
$R = \lambda_\alpha T$
Vestibular
Fast
Accurate
Inaccurate

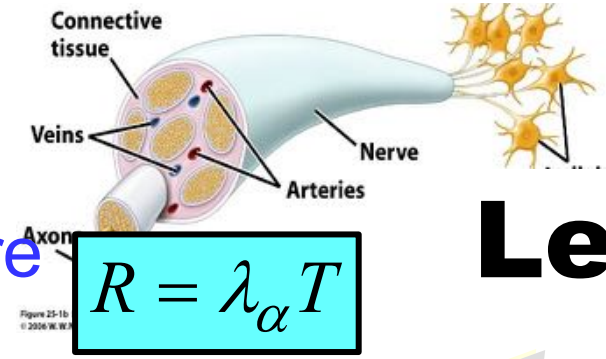

$(2^V - |a|)^{-1}$
$+\delta\left(\sum_{i=1}^{T}|a^{i-1}| + |a^T|(2^{\lambda T} - |a|)^{-1}\right)$
Laws
Theory
Levels
$R = \lambda_\alpha T$
Easy


$(2^V - |a|)^{-1}$
Diversity enabled Sweet Spot
$+\delta\left(\sum_{i=1}^{T}|a^{i-1}| + |a^T|(2^{\lambda T} - |a|)^{-1}\right)$
Architecture
Laws
Theory
Levels
$R = \lambda_\alpha T$
Diverse
Easy


Architecture
Layers
Diversity enabled Sweet Spot
Laws
Theory
Levels
Diverse
Slow
Flexible
Rigid
Nerves
Connective tissue
Veins
Nerve
Axons
Slow
Optic
Vestibular
Fast
Accurate
Inaccurate
L
S
M
G
T

trail
Layers
Slow
Fast
Diverse
bumps
Accurate
Flexible
Inaccurate
Rigid


Slow
Optic
Nerves
Architecture
Law
Fast
Diverse
Vestibular
Accurate
Inaccurate


Connective tissue
Veins
Nerve
Arteries
Axon
$R = \lambda_\alpha T$

Level

H
V
r
Theory
T
M
S
G
trail
$+\left(2^V - |a|\right)^{-1}$
bumps
$\delta\left(\sum_{i=1}^{T}|a^{i-1}| + |a^T|\left(2^{\lambda T} - |a|\right)^{-1}\right)$

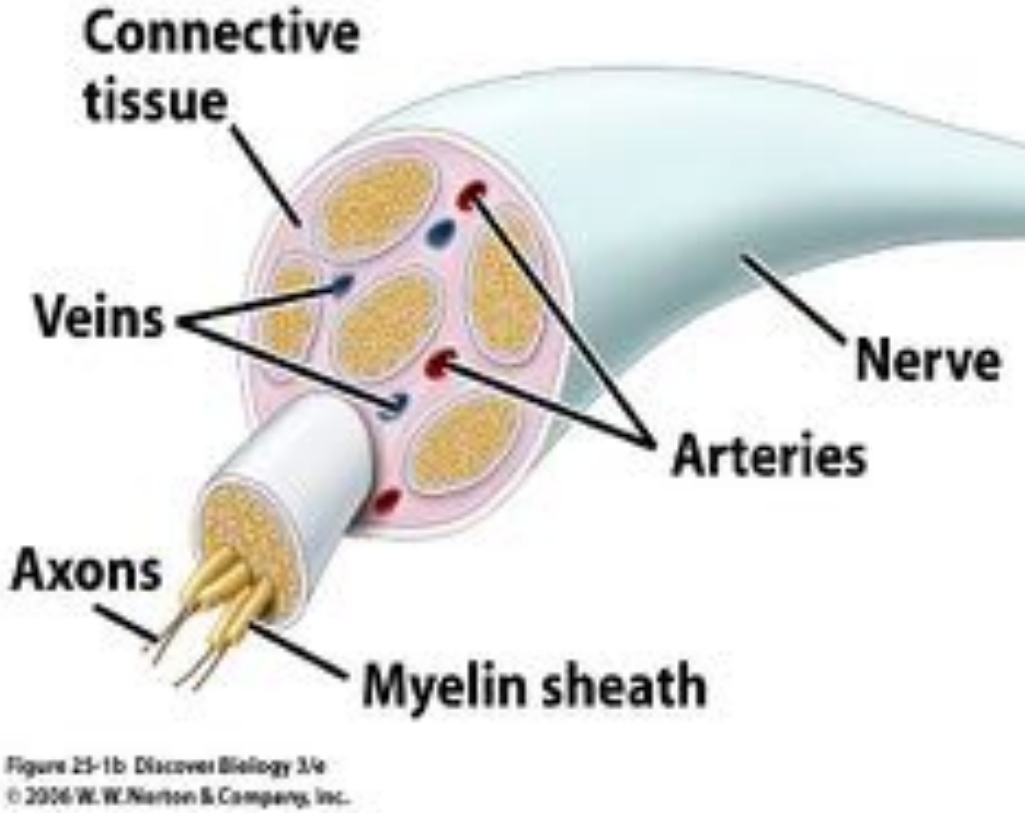


Figure 25-1b Discover Biology 3/e
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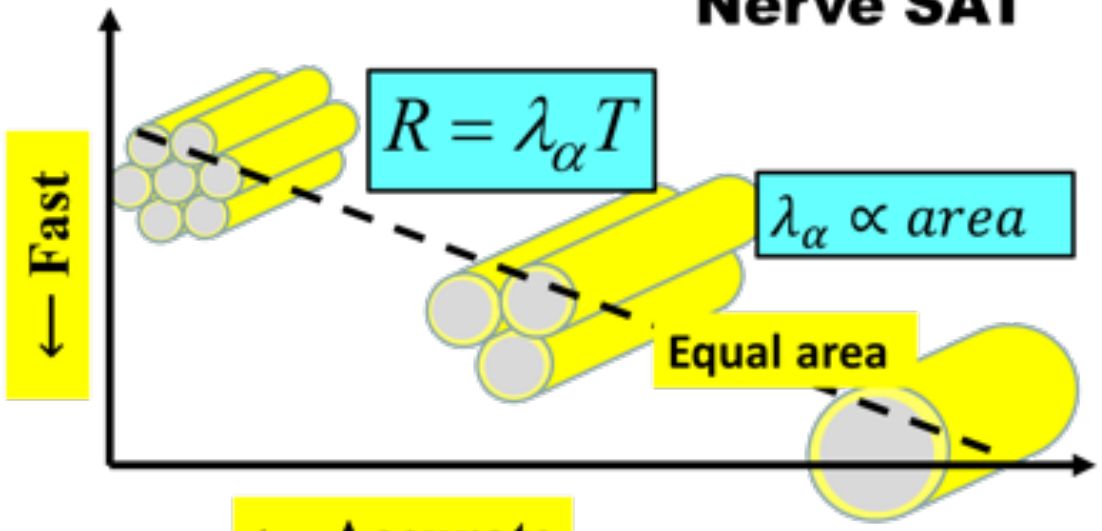
log(*T*)

log(delay)

Nerve SAT

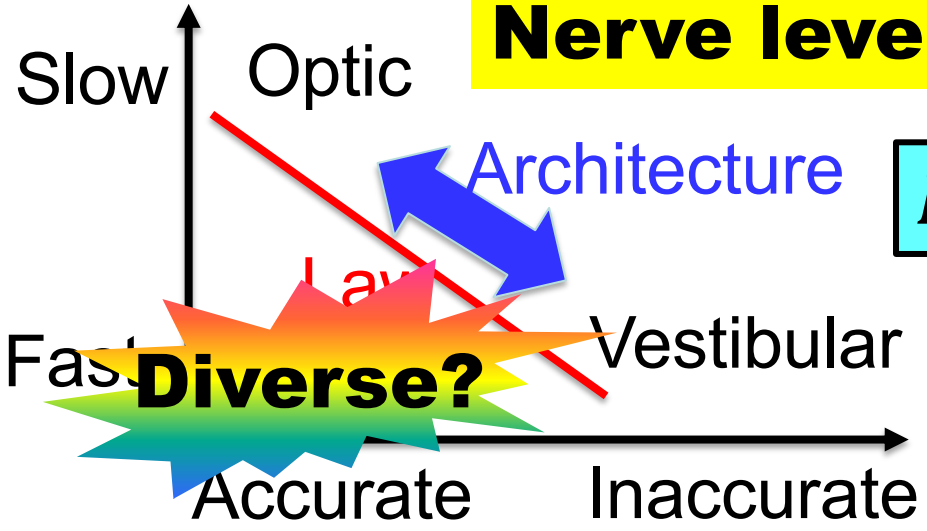


-log(*R*)

-log(bandwidth)

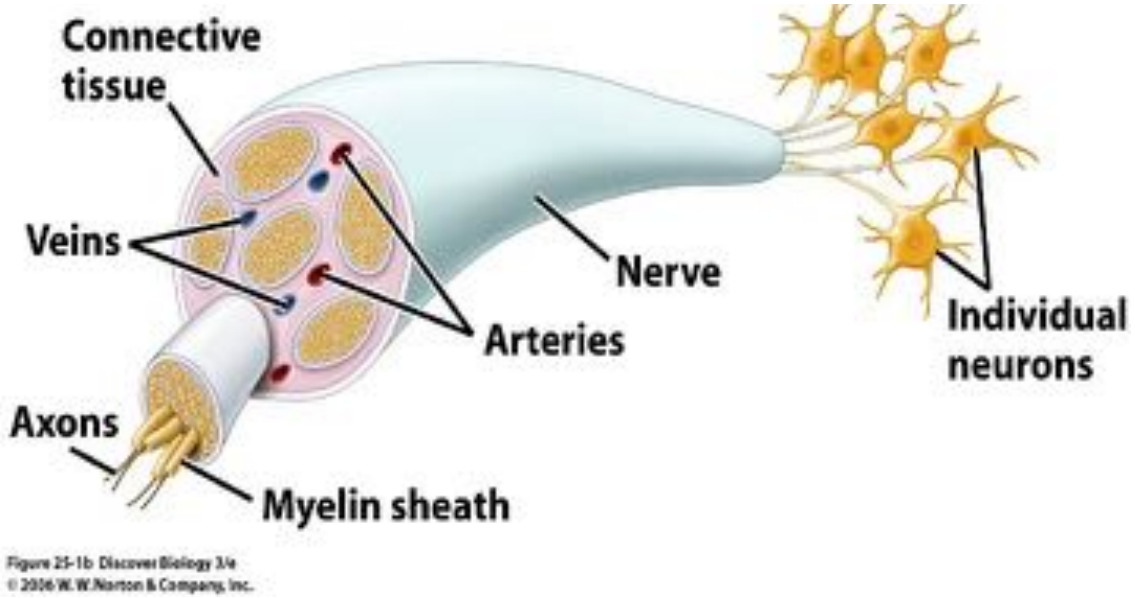
Yorie Nakahira
Terry Sejnowski
Simon Laughlin
(Peter Sterling)

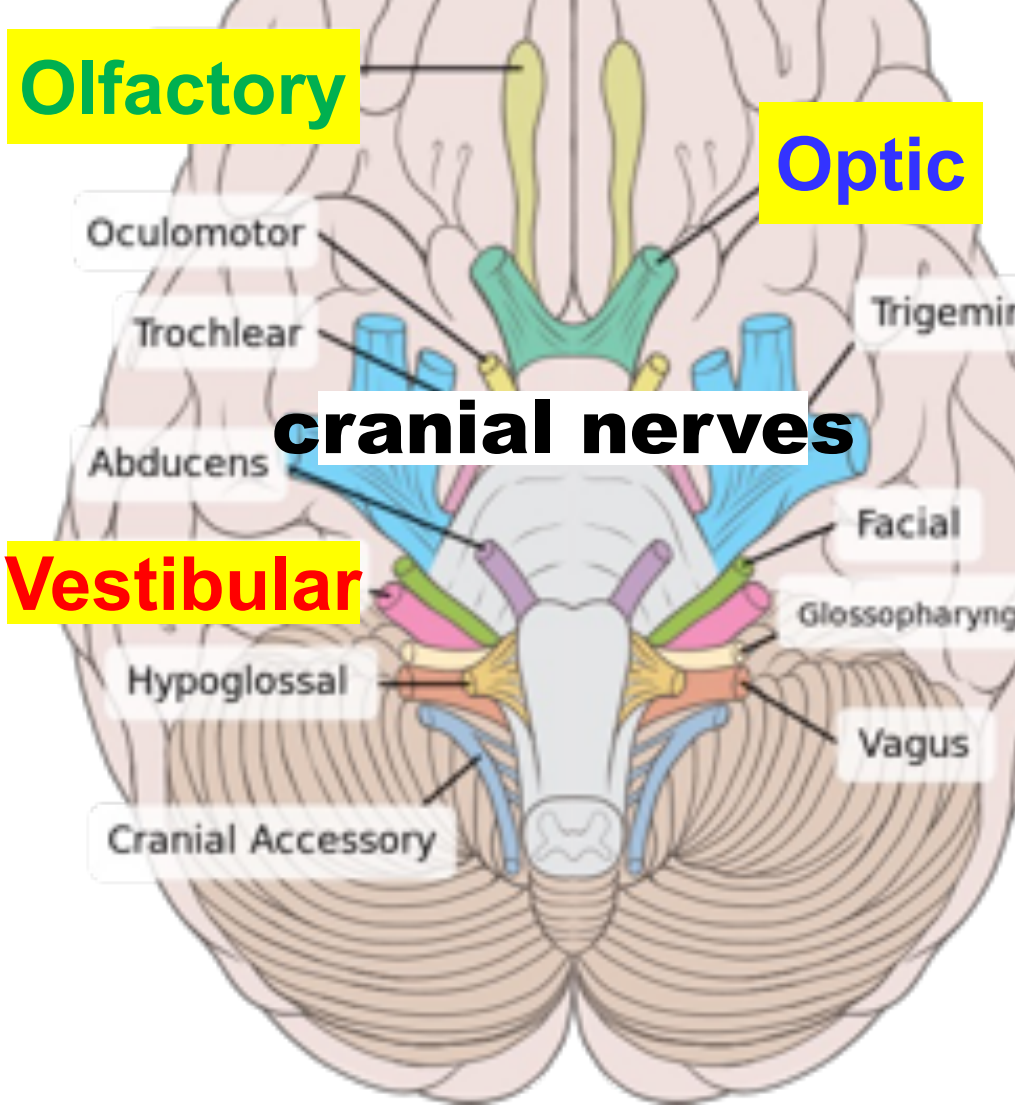
Nerve level?

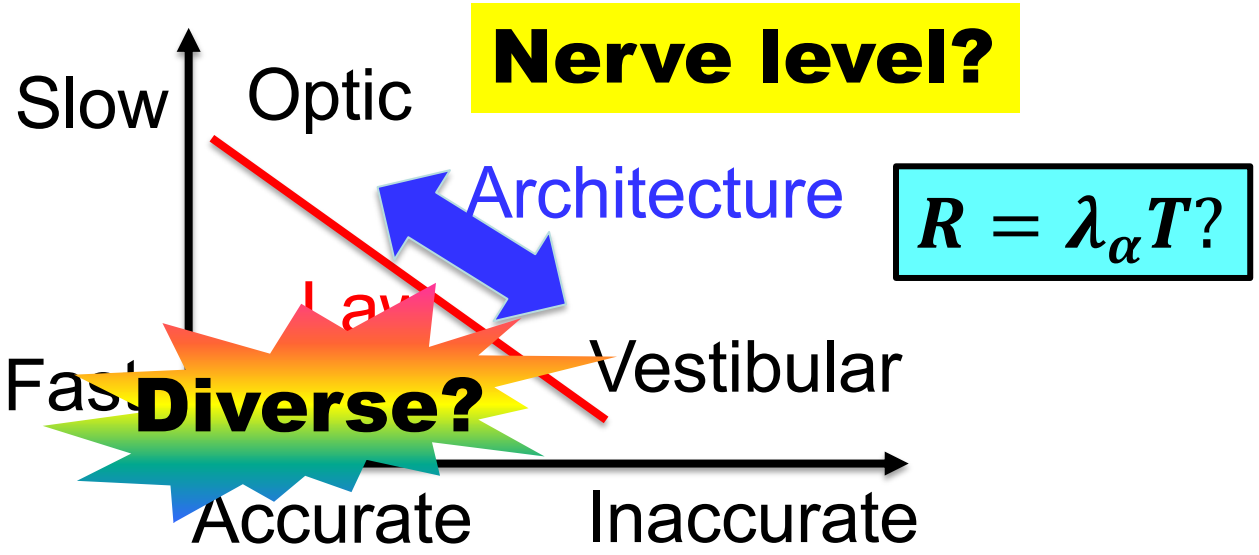


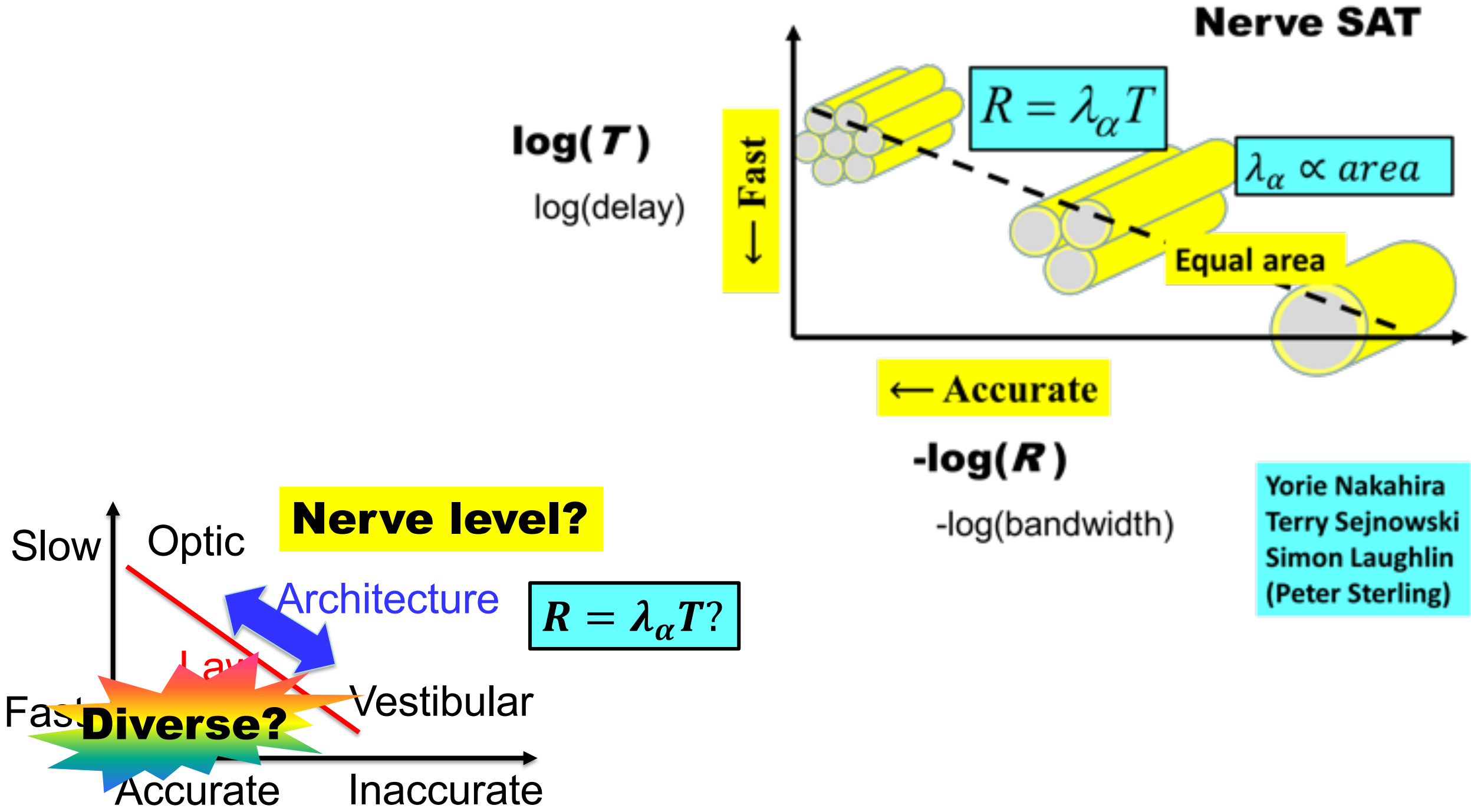
$R = \lambda_\alpha T$?

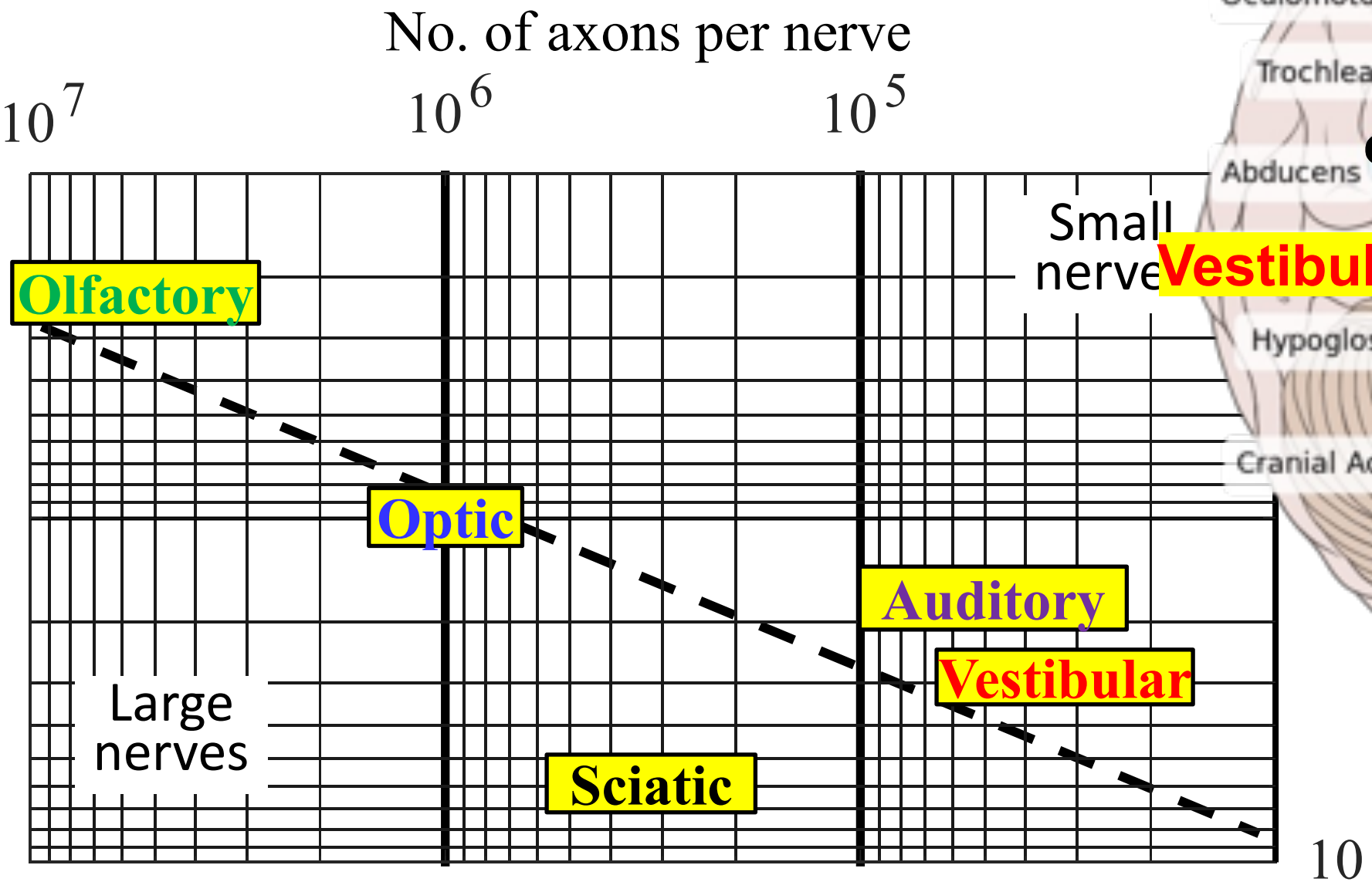
Diverse?

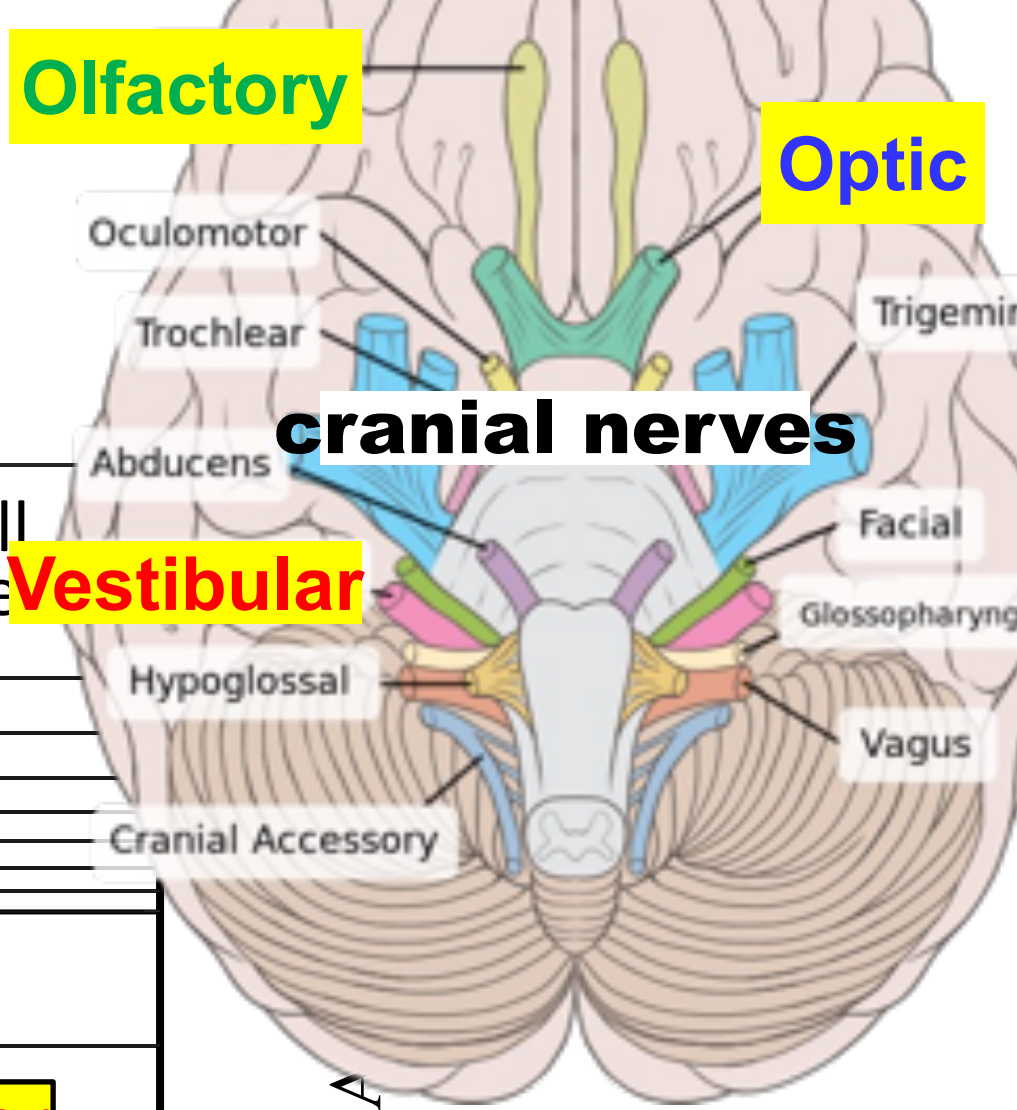

Connective tissue
Veins
Arteries
Nerve
Individual neurons
Axons
Myelin sheath

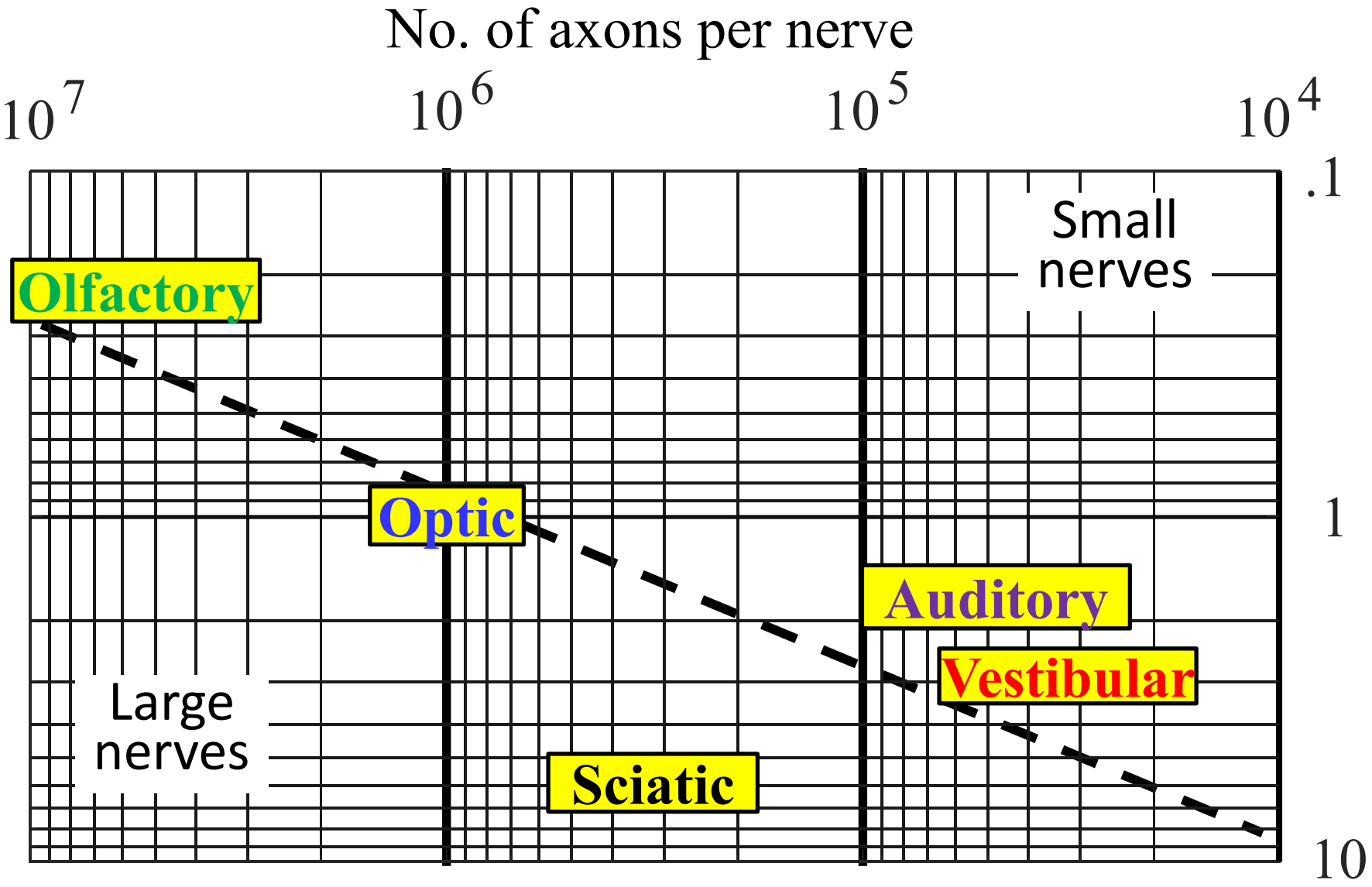

Olfactory
Optic
Oculomotor
Trochlear
Trigemir
cranial nerves
Abducens
Facial
Vestibular
Glossopharyng
Hypoglossal
Vagus
Cranial Accessory

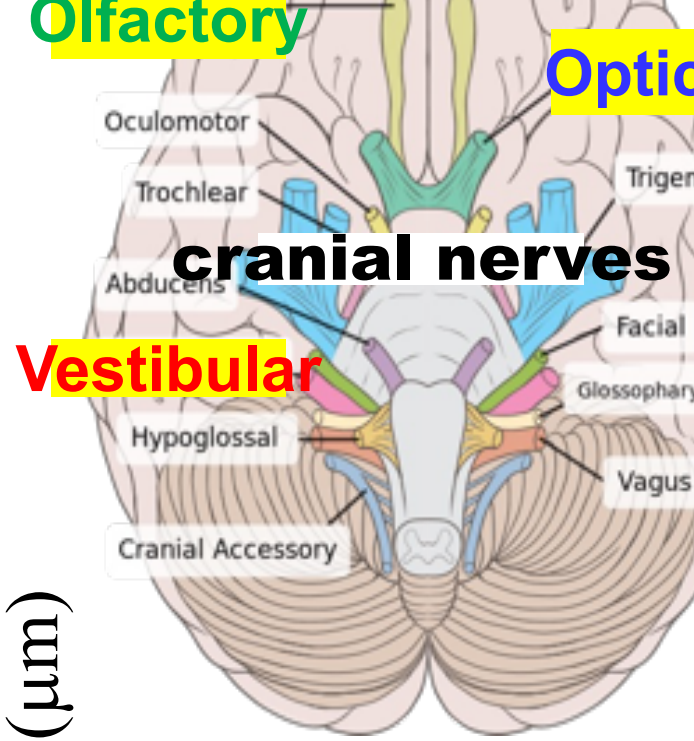

Slow
Optic
Nerve level?
Architecture
$R = \lambda_\alpha T$?
Fast
Vestibular
Diverse?
Accurate
Inaccurate

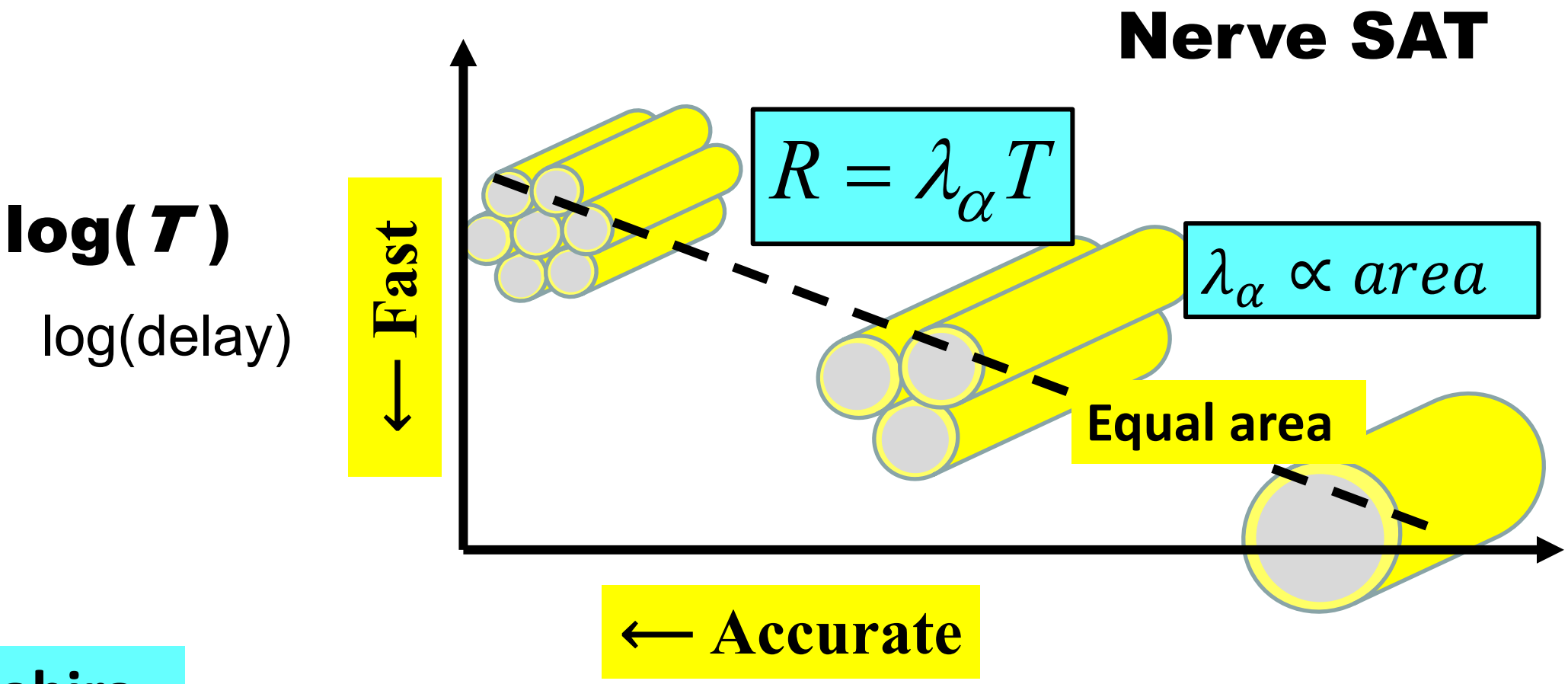

Nerve SAT
log(T)
log(delay)
← Fast
$R = \lambda_\alpha T$
$\lambda_\alpha \propto area$
Equal area
← Accurate
-log(R)
-log(bandwidth)
Yorie Nakahira
Terry Sejnowski
Simon Laughlin
(Peter Sterling)
Nerve level?
Slow
Optic
Architecture
$R = \lambda_\alpha T$?
Vestibular
Diverse?
Accurate
Inaccurate


No. of axons per nerve
10^7
10^6
10^5
Small nerve
Olfactory
Optic
Auditory
Vestibular
Sciatic
Large nerves
Avg. A
10


Olfactory
Optic
Oculomotor
Trochlear
Trigemir
cranial nerves
Abducens
Facial
Vestibular
Glossopharyng
Hypoglossal
Vagus
Cranial Accessory

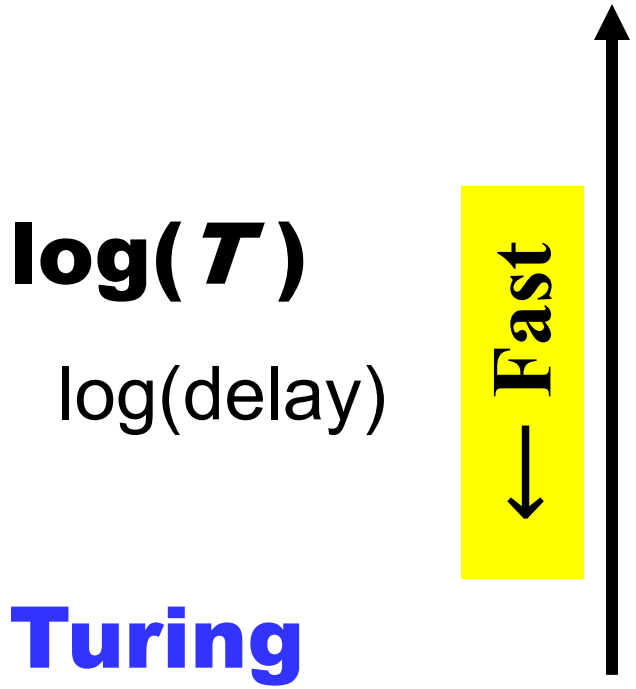

No. of axons per nerve
10^7
10^6
10^5
10^4
Olfactory
Optic
Auditory
Vestibular
Sciatic
Small nerves
Large nerves
Avg. Axon diam. (μm)
.1
1
10


Olfactory
Optic
Oculomotor
Trochlear
Trigem
cranial nerves
Abducens
Facial
Vestibular
Glossopharyn
Hypoglossal
Vagus
Cranial Accessory



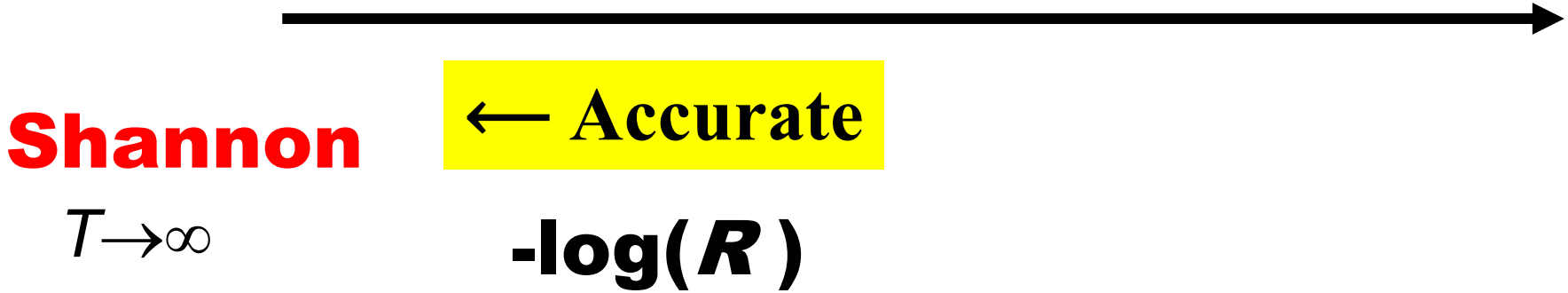
Yorie Nakahira
Terry Sejnowski
Simon Laughlin
(Peter Sterling)

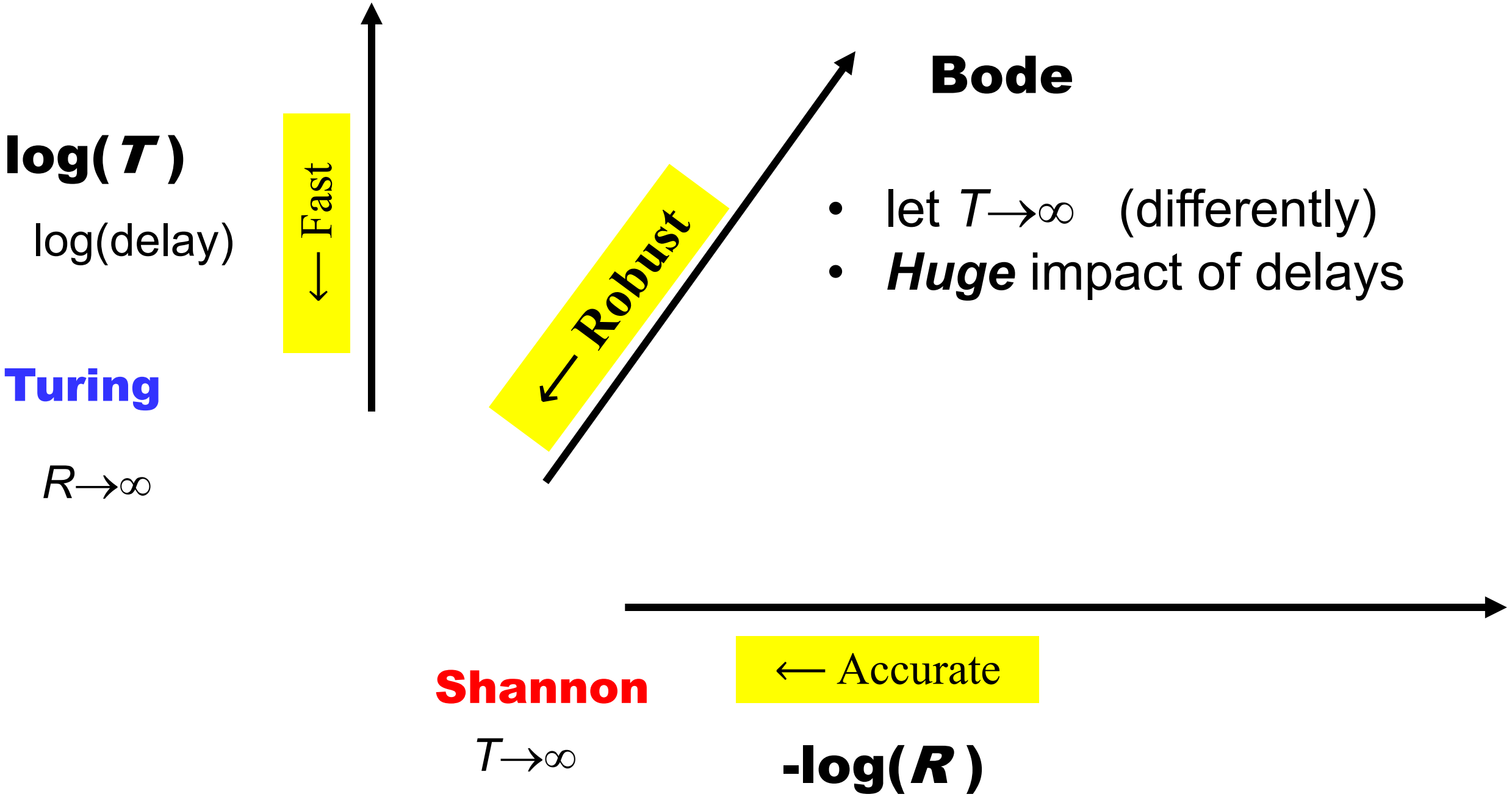
~~Nerve SAT~~



Both Turing and Shannon

- let $T \to \infty$ (differently)
- Don't worry about delays



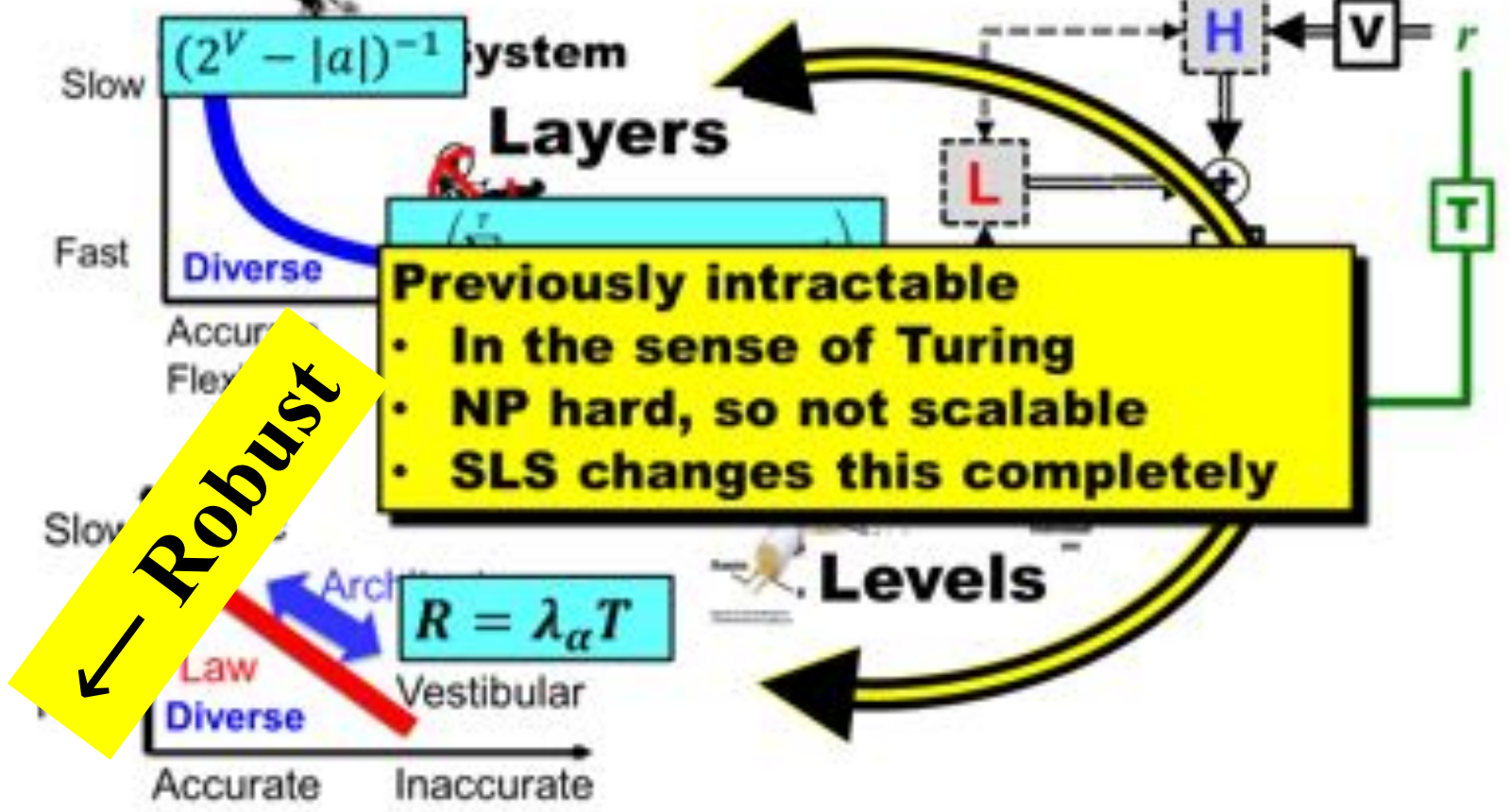

log(T)
log(delay)
← Fast
Turing
R→∞
← Robust
Bode
• let T→∞ (differently)
• Huge impact of delays
Shannon
T→∞
← Accurate
-log(R)

log(*T*)

log(delay)

← Fast

Turing



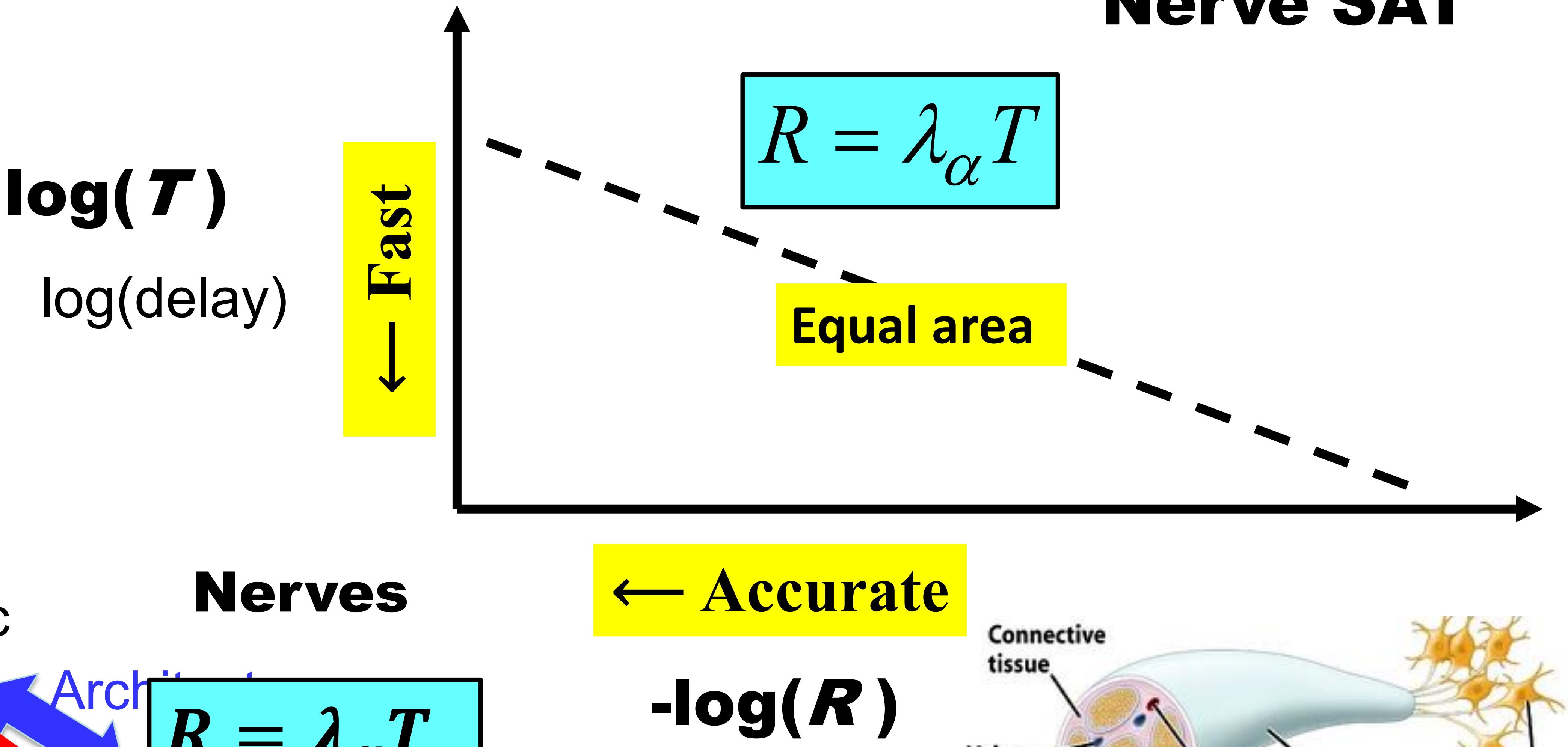
- **Lost connection with Shannon**
- **Much more needed**

Shannon

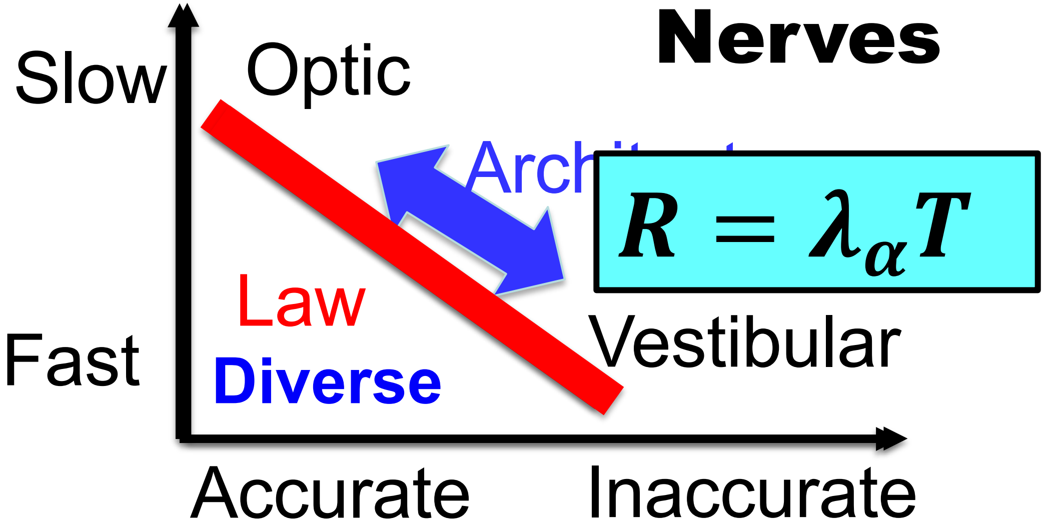
← Accurate

-log(*R*)

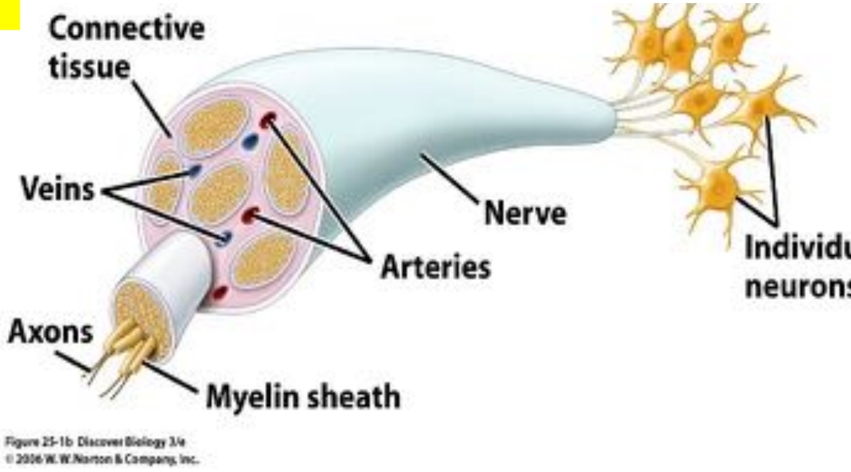
Nerve SAT



$R = \lambda_\alpha T$
Equal area
log(*T*)
log(delay)
← Fast
← Accurate
-log(*R*)

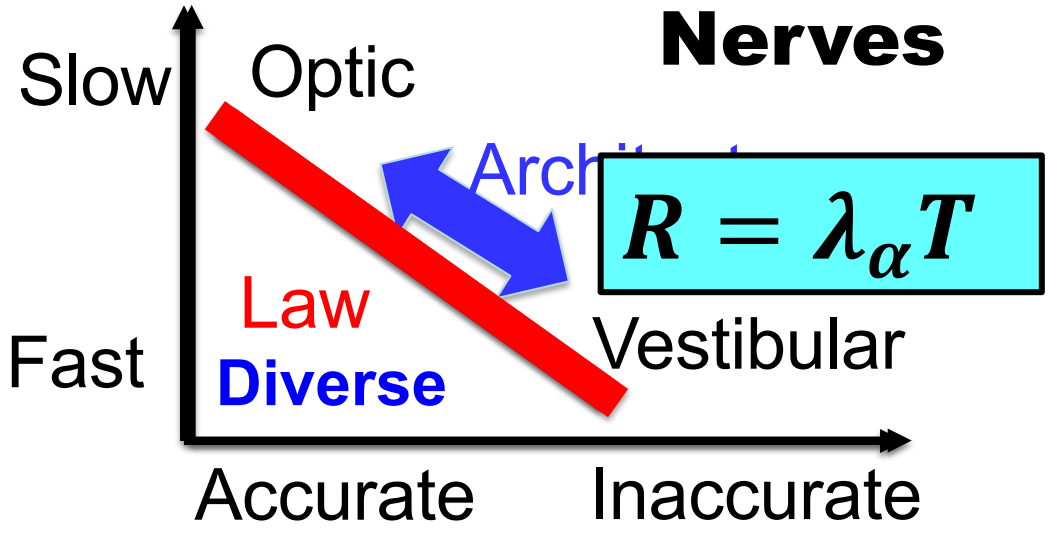


Nerves
Slow
Fast
Optic
Vestibular
Law
Diverse
$R = \lambda_\alpha T$
Accurate
Inaccurate

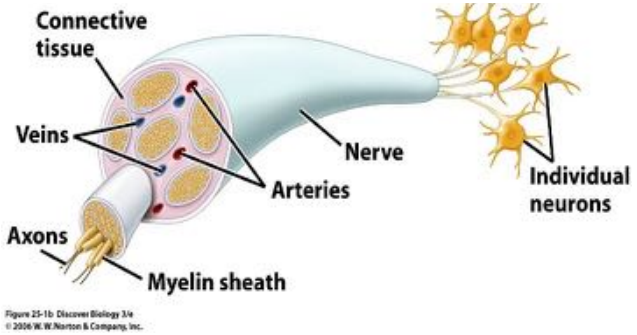


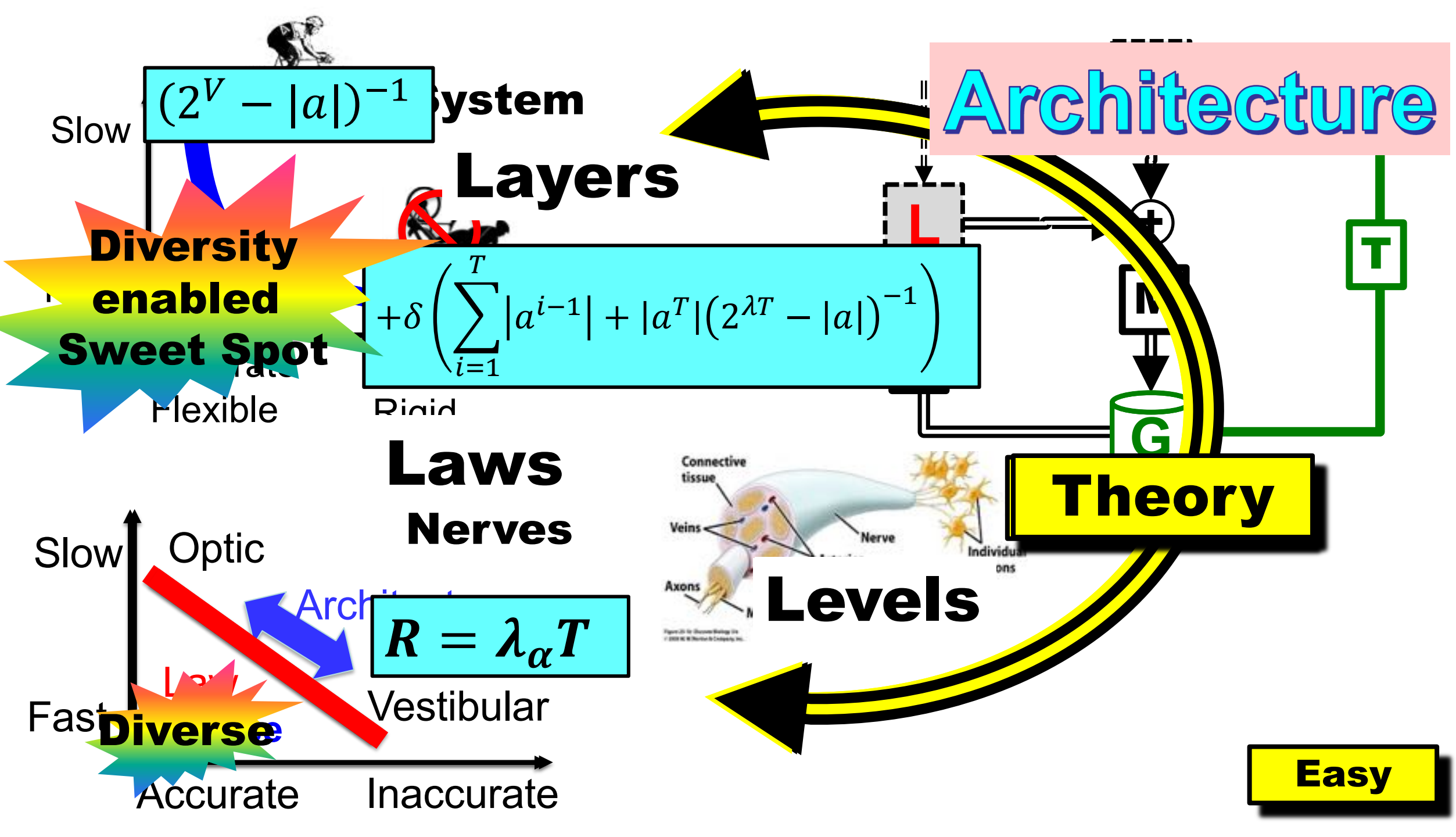
Connective tissue
Veins
Nerve
Arteries
Axons
Myelin sheath

Nerves



$$R = \lambda_{\alpha} T$$



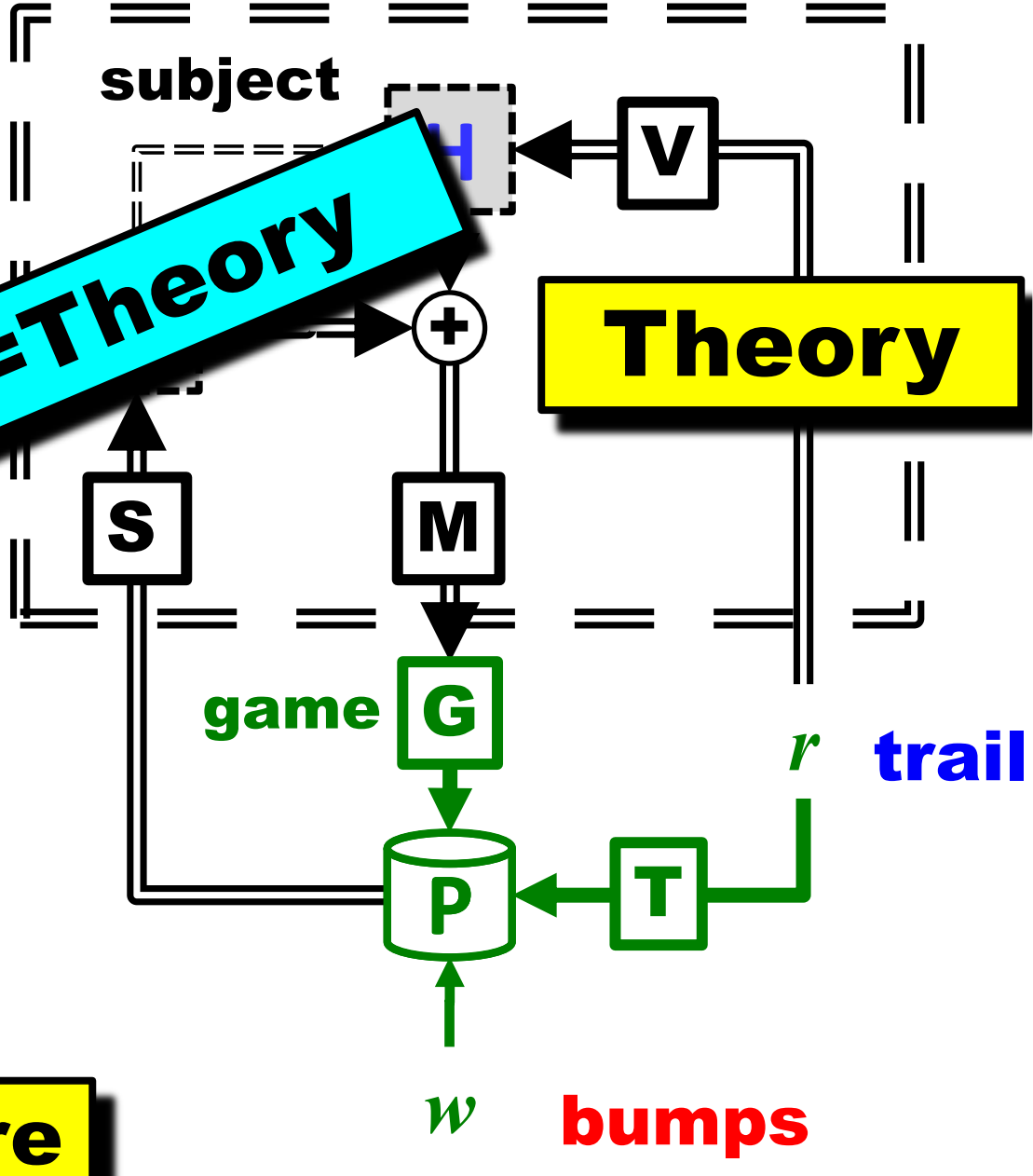

$(2^V - |a|)^{-1}$
Slow
ystem
Layers
Diversity enabled Sweet Spot
$+\delta\left(\sum_{i=1}^{T}|a^{i-1}| + |a^T|(2^{\lambda T} - |a|)^{-1}\right)$
Flexible
Rigid
L
N
T
G
Architecture
Theory
Laws
Nerves
Connective tissue
Veins
Nerve
Axons
Levels
Slow
Optic
Fast
Vestibular
Accurate
Inaccurate
$R = \lambda_\alpha T$
Diverse
Easy

Function

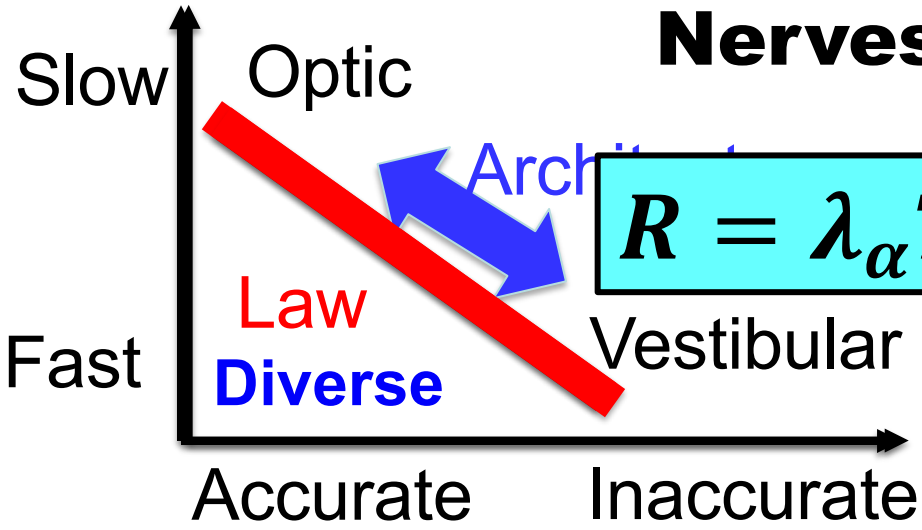
Bumps

Levels

Data=Theory



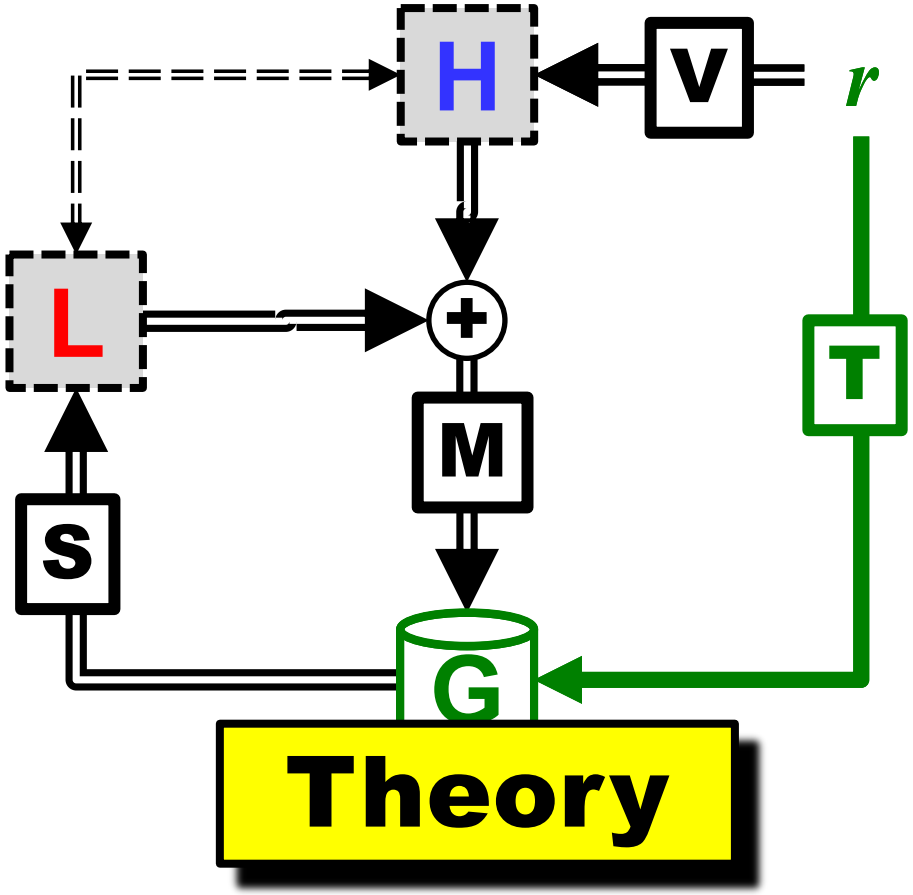
Nerves



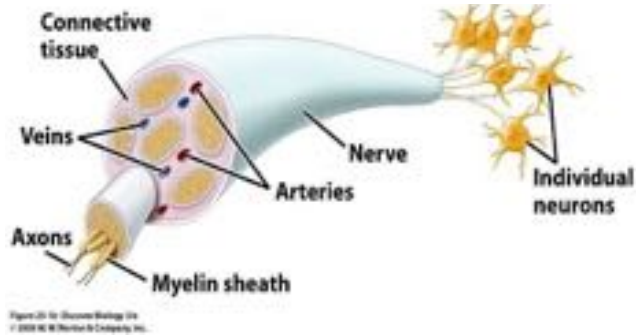
$$R = \lambda_{\alpha} T$$

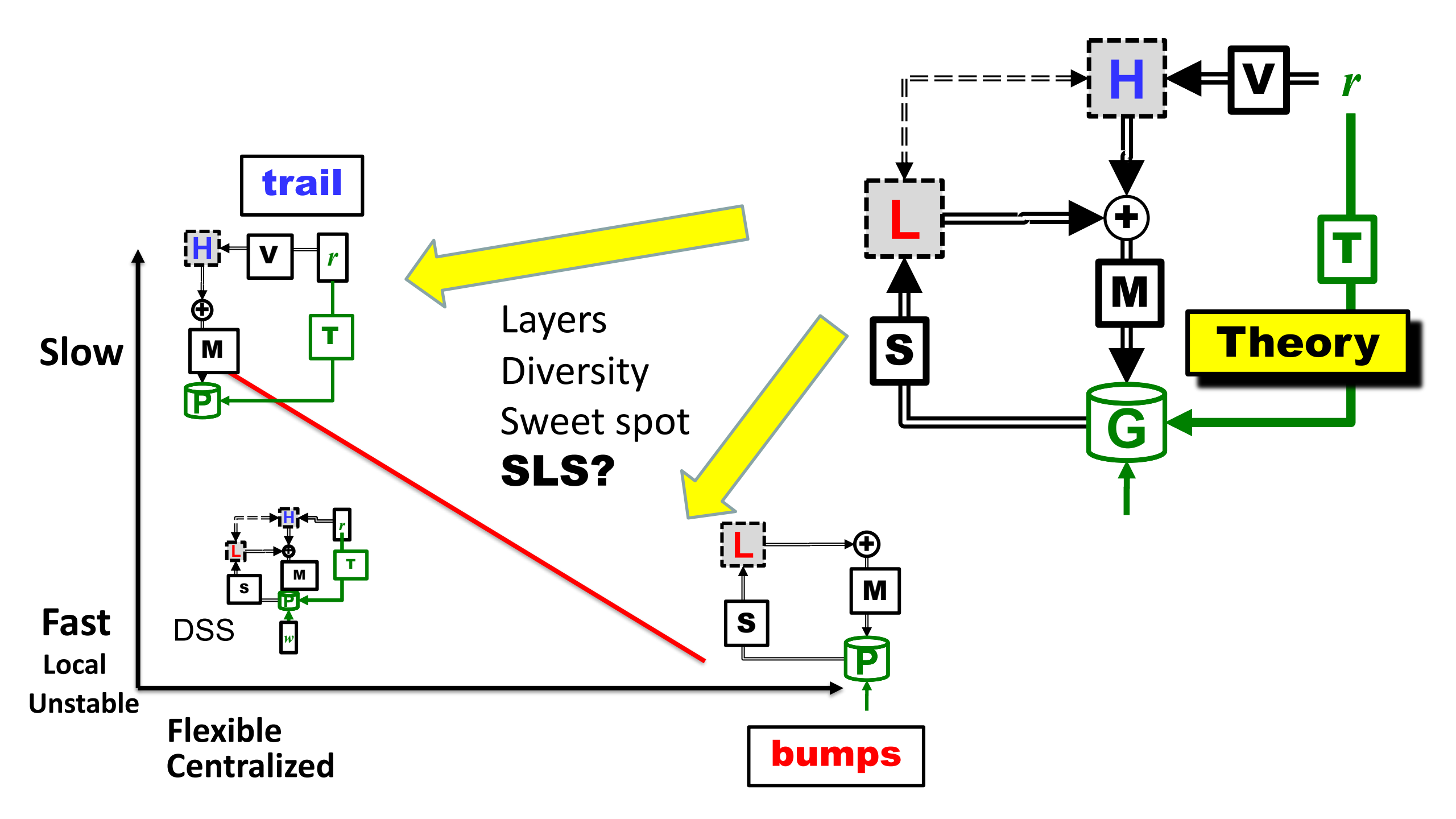
Hardware

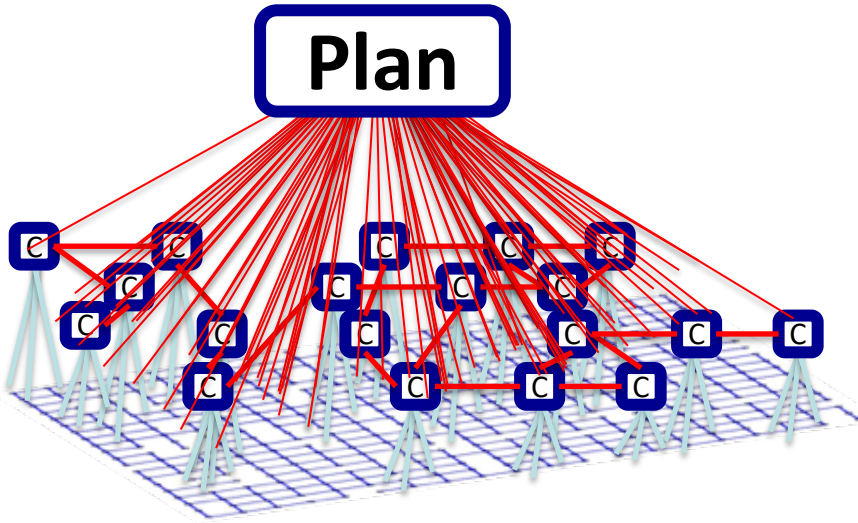
- Scalar trail and bumps
- Math is easy
- (Experiments are easy)
- **Has no additional *internal* structure (e.g. within cortex)**
- Beyond what is in the diagram
- What next?

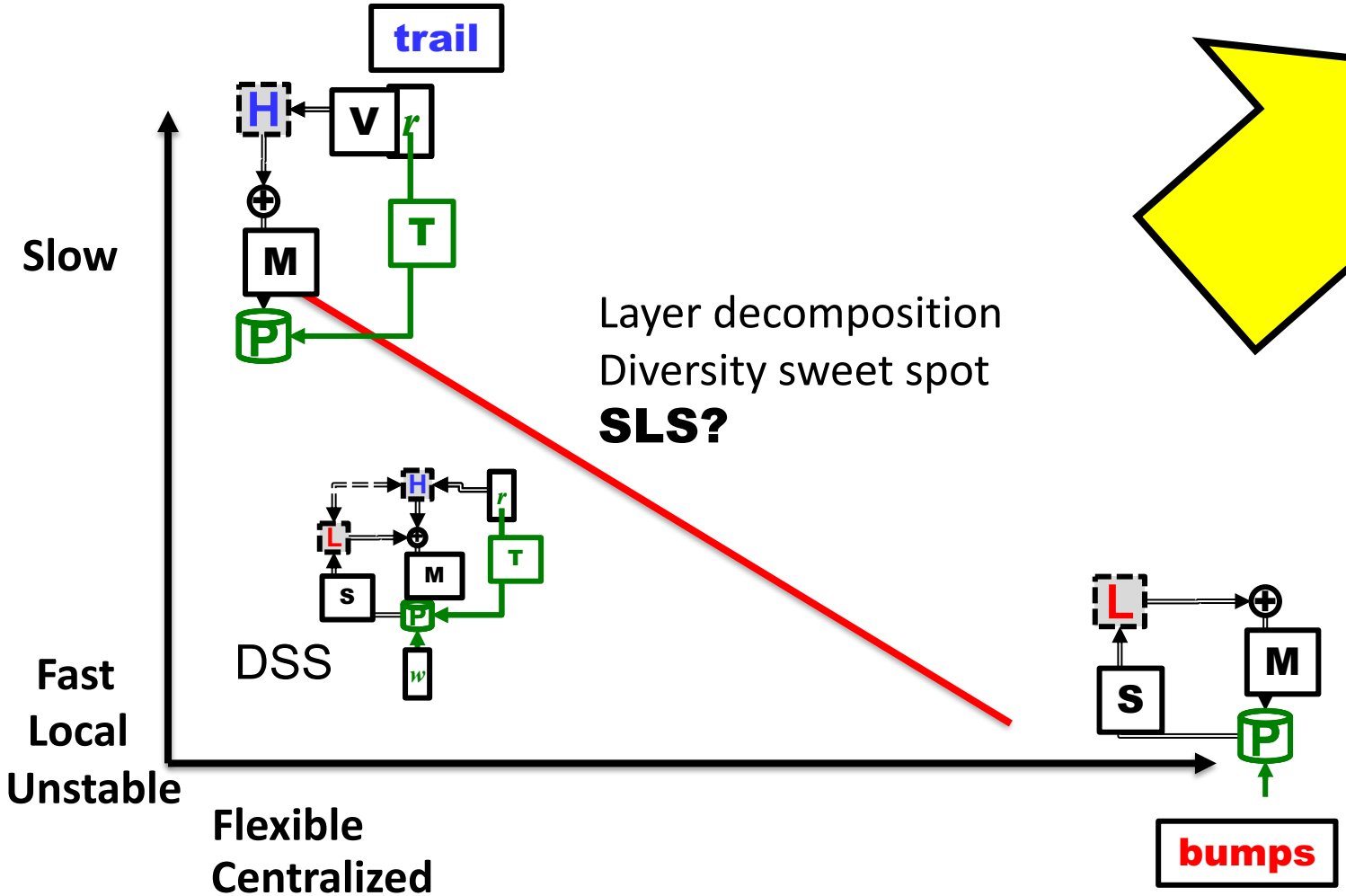


- **1 dimensional**
- **scalar trail**
- **scaler bump**




trail
H
V
r
M
T
P
Slow
Layers
Diversity
Sweet spot
SLS?
L
S
M
T
Theory
G
DSS
Fast
Local
Unstable
Flexible
Centralized
bumps


Plan
C


trail
H
V
r
T
M
P
Slow
Fast
Local
Unstable
Flexible
Centralized
Layer decomposition
Diversity sweet spot
SLS?
DSS
L
S
M
P
bumps