Steps Towards Knowledgeable Neuroprostheses

Patrick Pilarski

Division of Physical Medicine & Rehabilitation, BLINC Lab,
Alberta Innovates Centre for Machine Learning, and
Reinforcement Learning and Artificial Intelligence Laboratory

(and with Sherstan, Machado, White)

UNIVERSITY OF ALBERTA

EDMONTON·ALBERTA·CANADA

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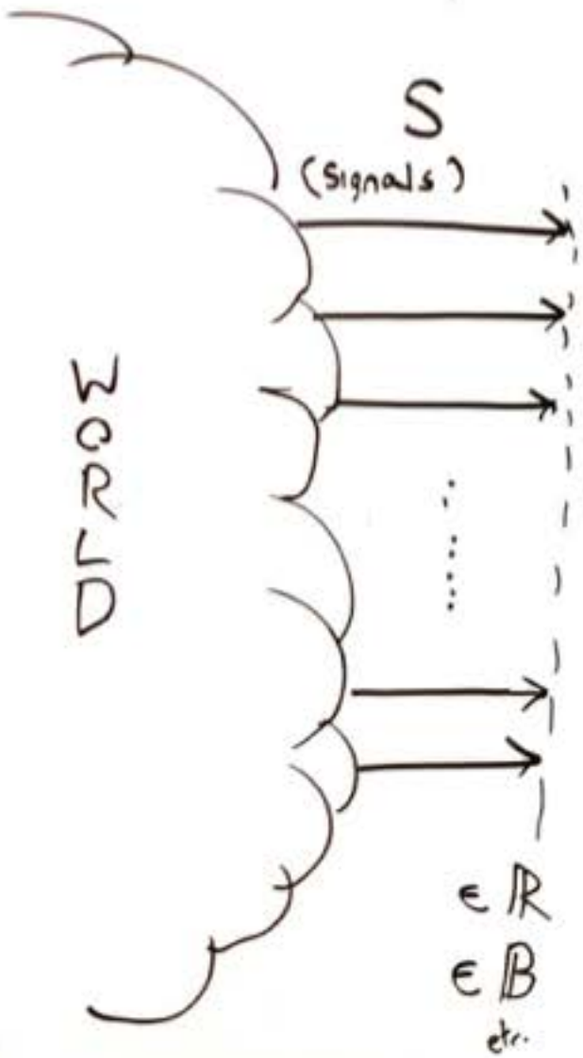
Modular Prosthetic Limb (MPL):

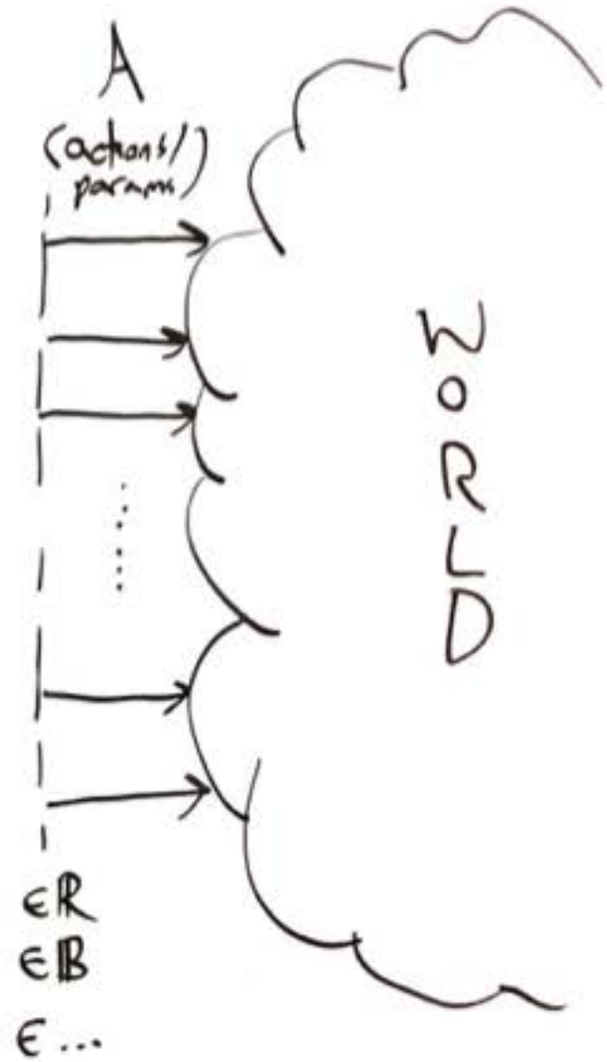
22-DOF robot arm.

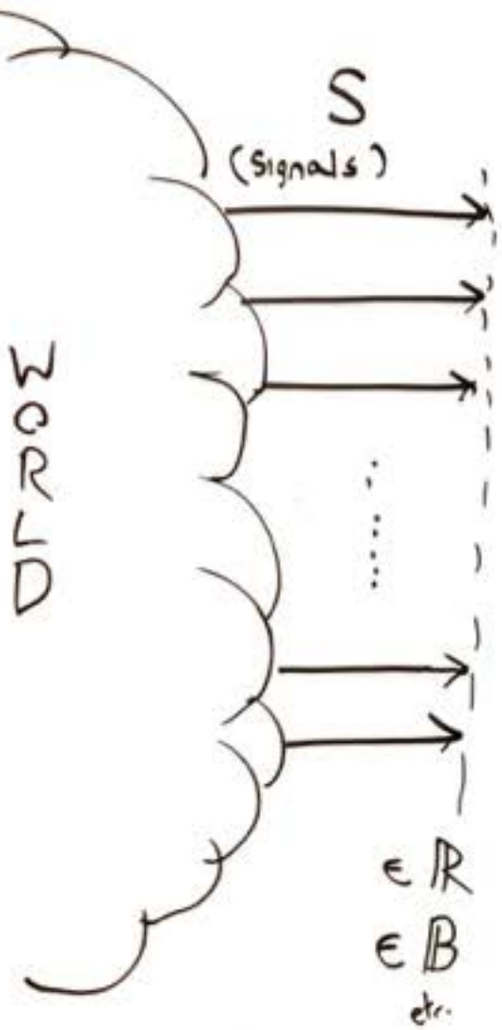
100+ sensory percepts.

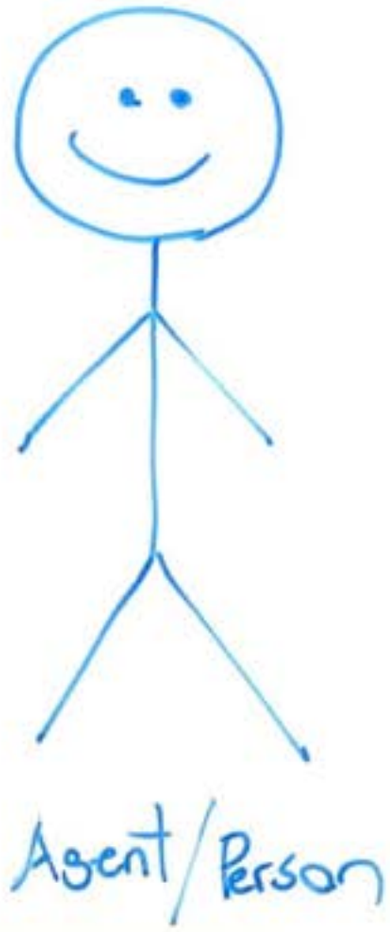
Real-time data stream.

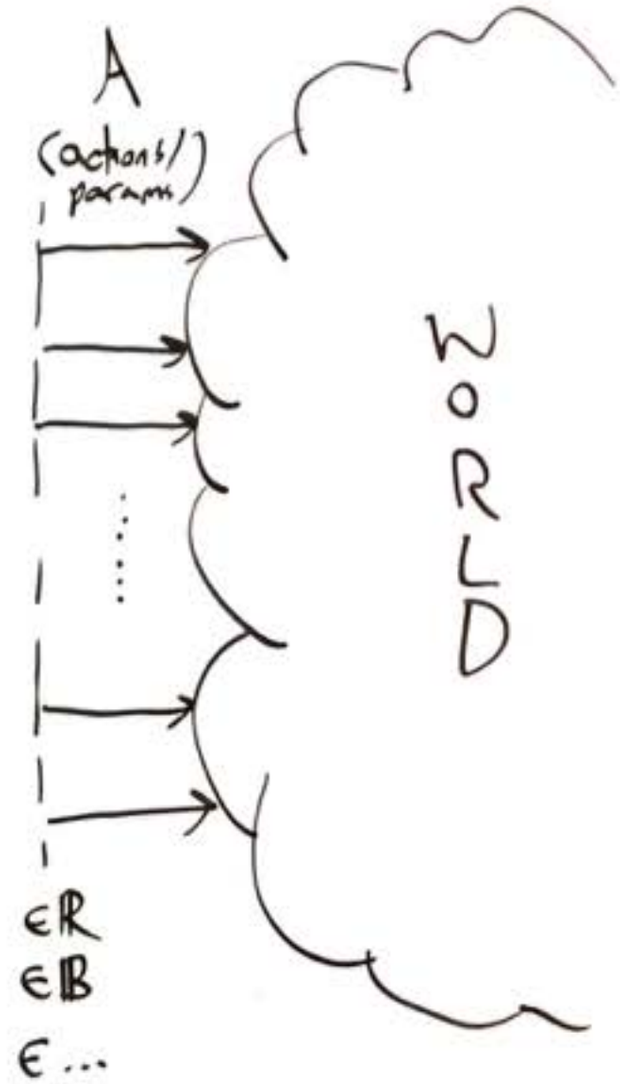
Multiple human-machine interface approaches: EMG, data glove, etc.

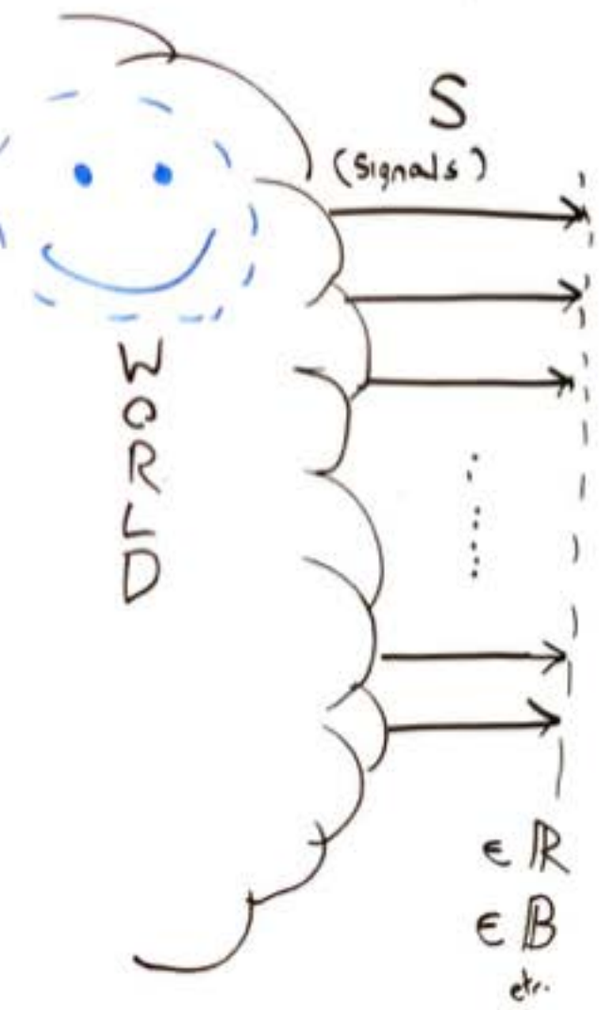

S
(signals)
WORLD
∈ ℝ
∈ 𝔹
etc.


A
(actions/
params)
WORLD
∈ ℝ
∈ 𝔹
∈ ...

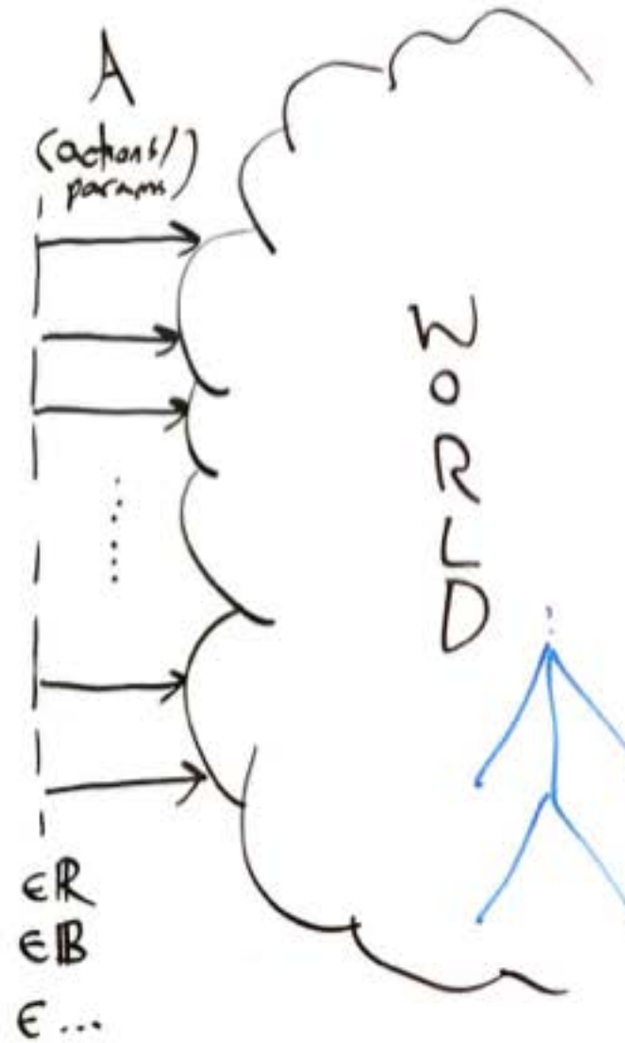

S
(Signals)
WORLD
∈ ℝ
∈ 𝔹
etc.

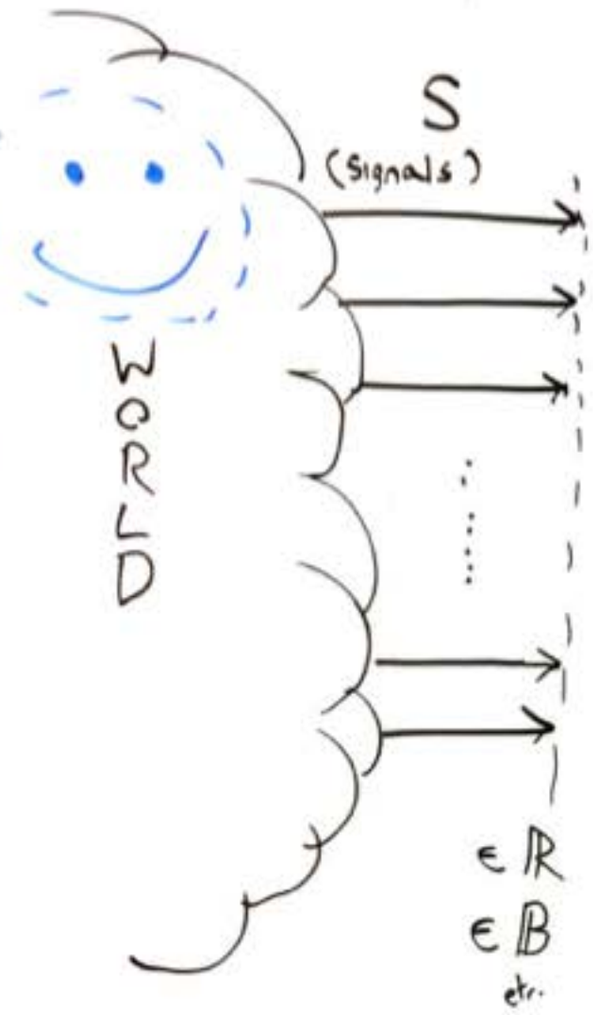

Agent/Person


A
(actions/
params)
WORLD
∈ ℝ
∈ 𝔹
∈ ...

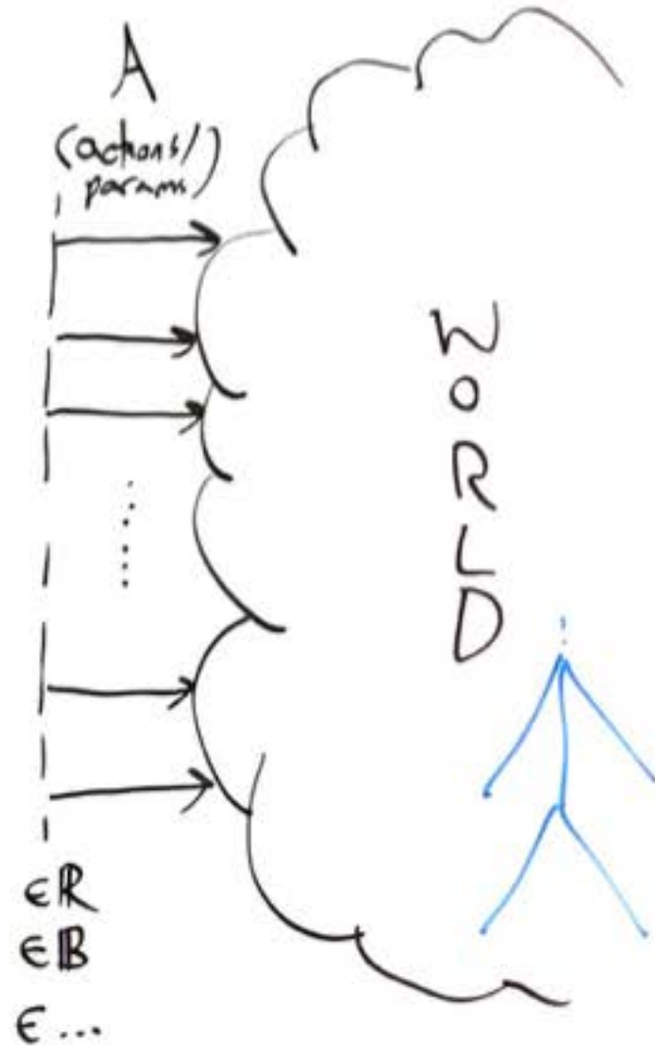


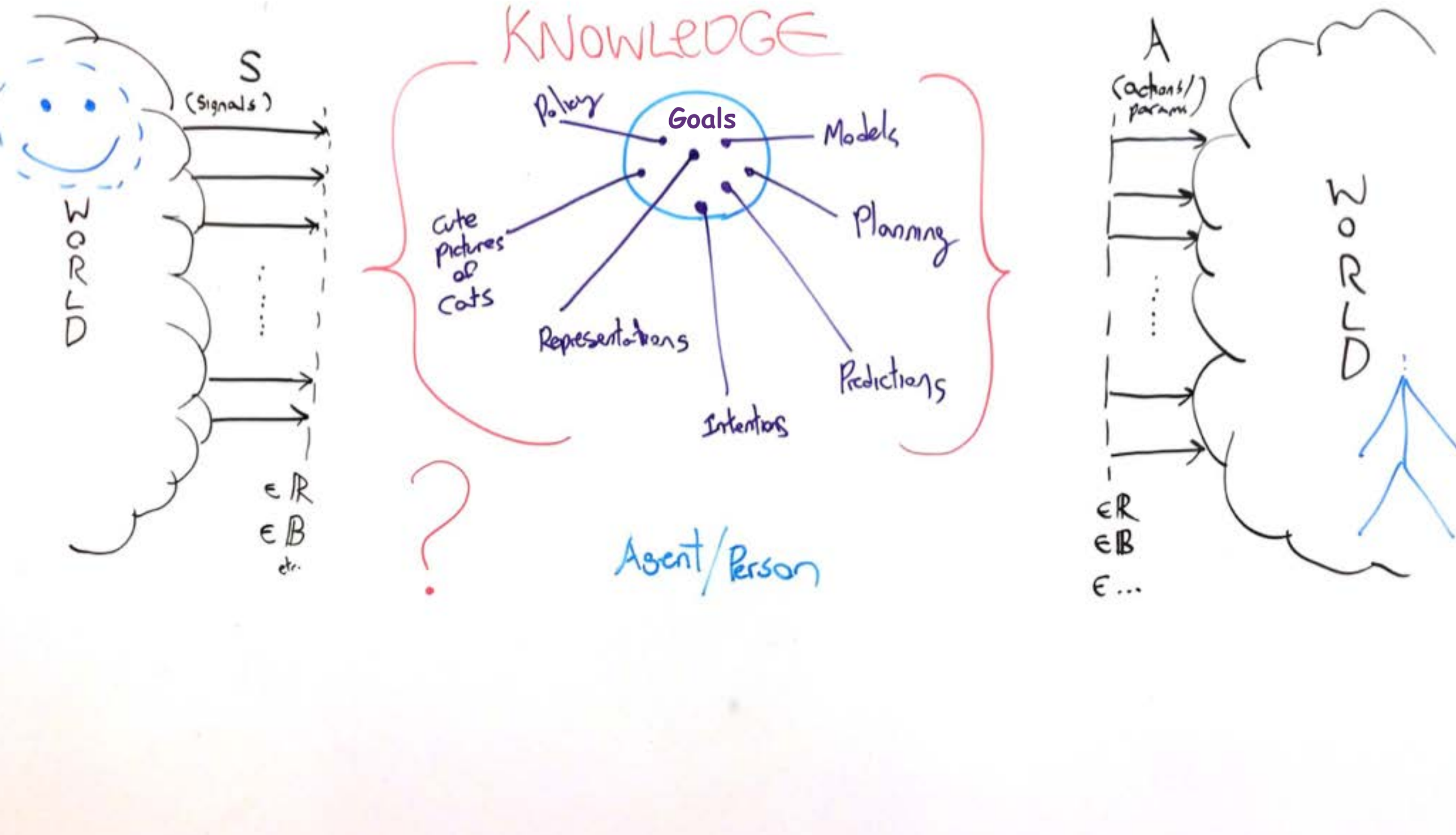
Agent/Person

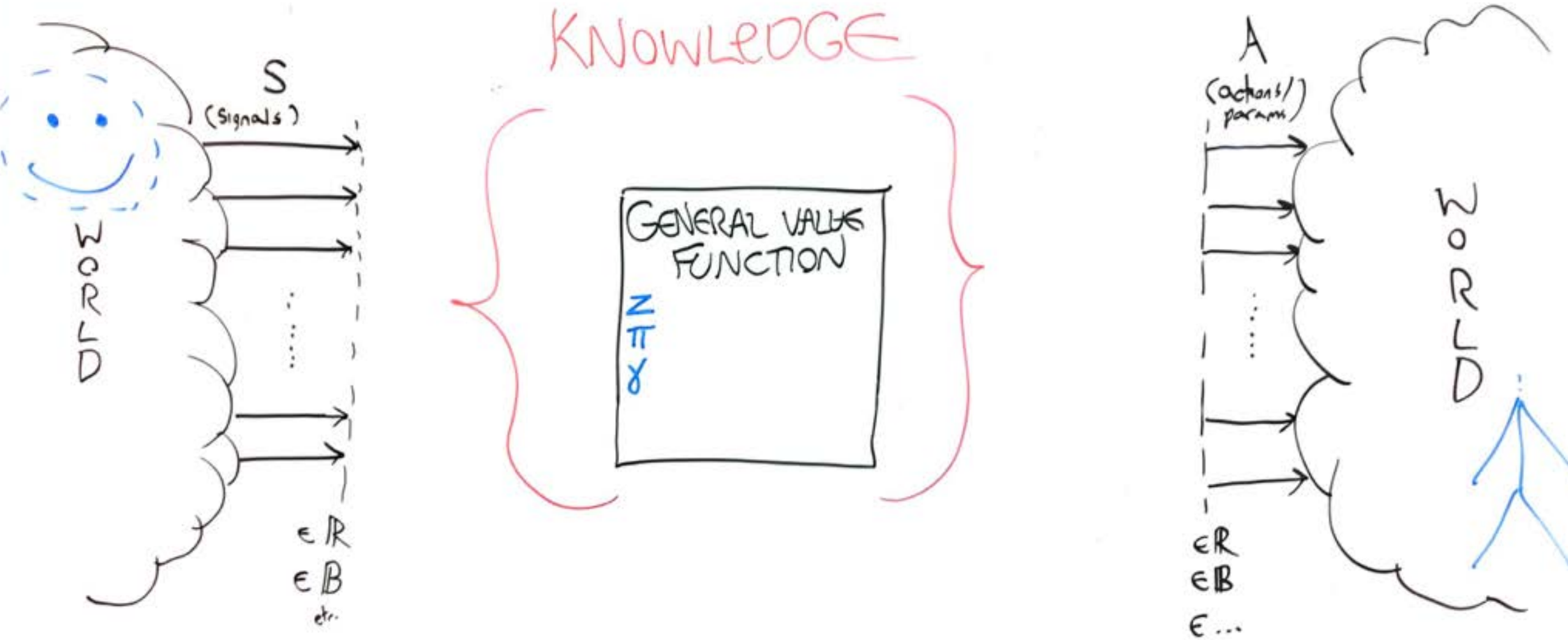


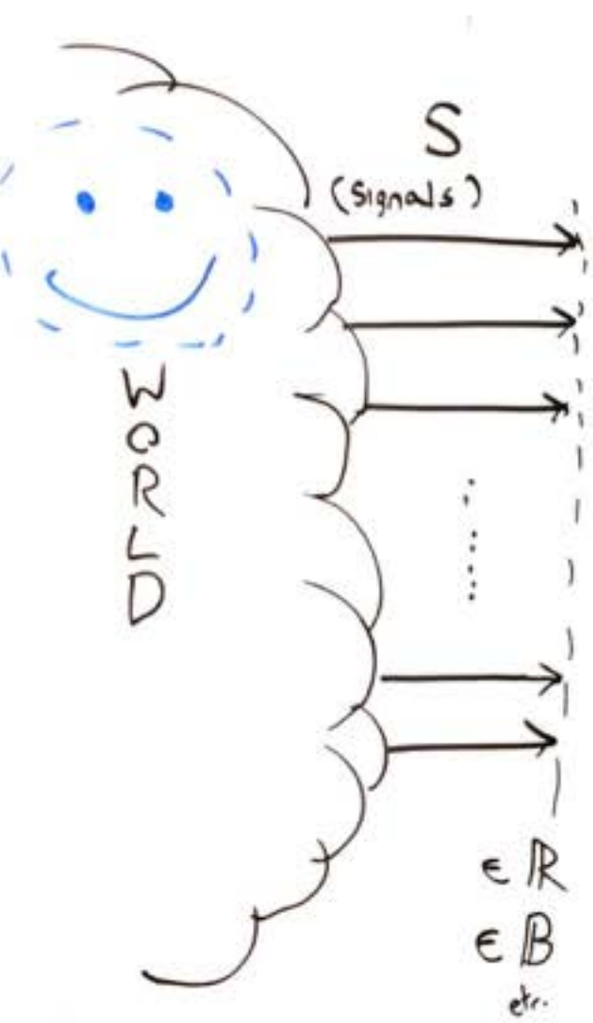


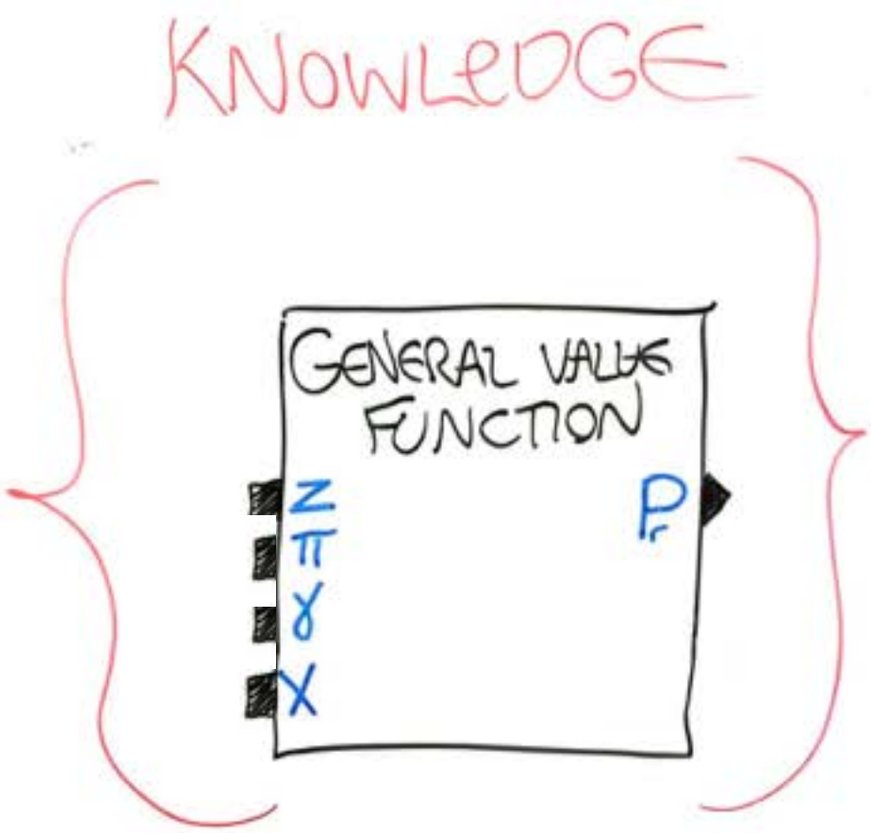
Agent/Person

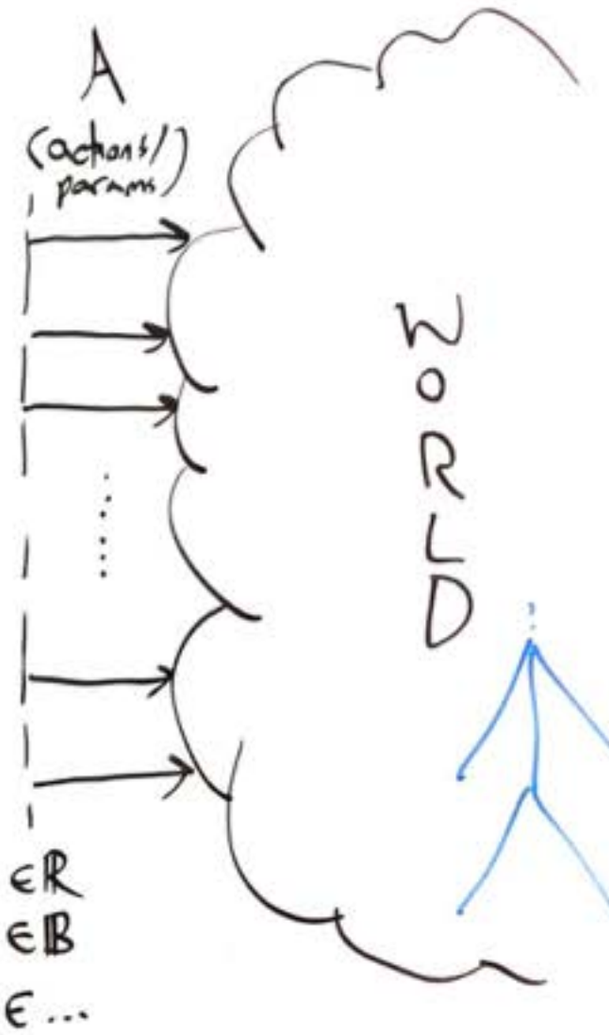


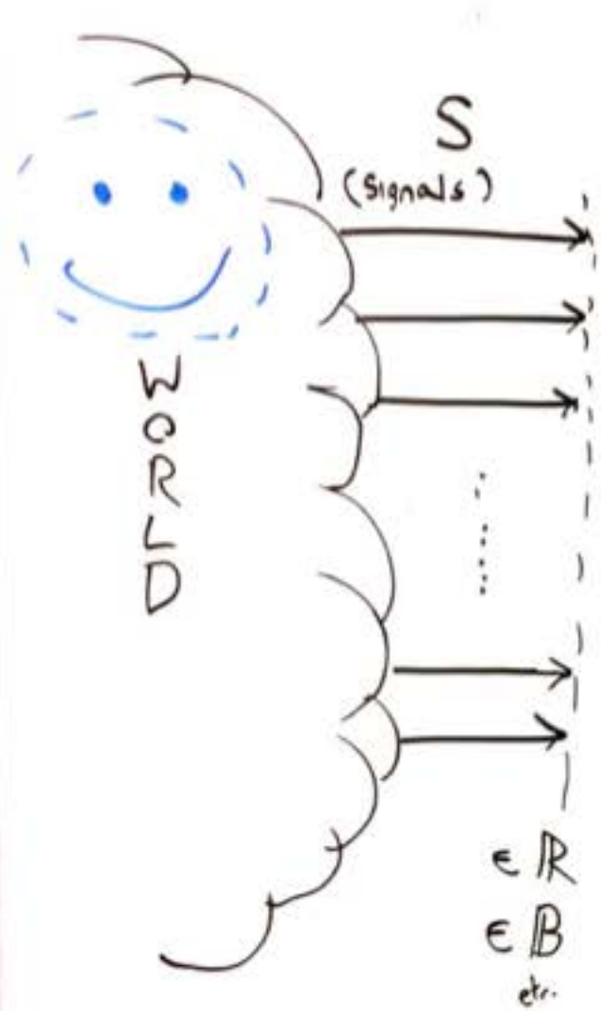

S
(Signals)
WORLD
∈ ℝ
∈ 𝔹
etc.
KNOWLEDGE
Policy
Goals
Models
Cute pictures of cats
Planning
Representations
Intentions
Predictions
?
Agent/Person
A
(actions/ params)
WORLD
∈ ℝ
∈ 𝔹
∈ ...

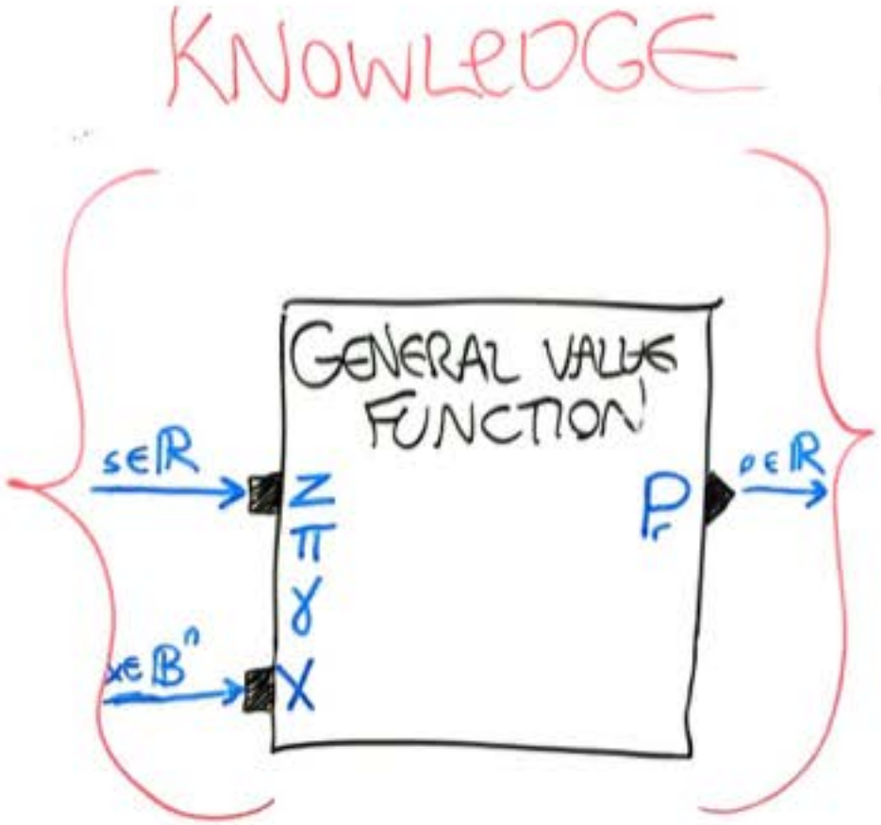

KNOWLEDGE
S
(Signals)
WORLD
∈ ℝ
∈ 𝔹
etc.
GENERAL VALUE FUNCTION
AN
π
γ
A
(actions/ params)
WORLD
∈ ℝ
∈ 𝔹
∈ ...

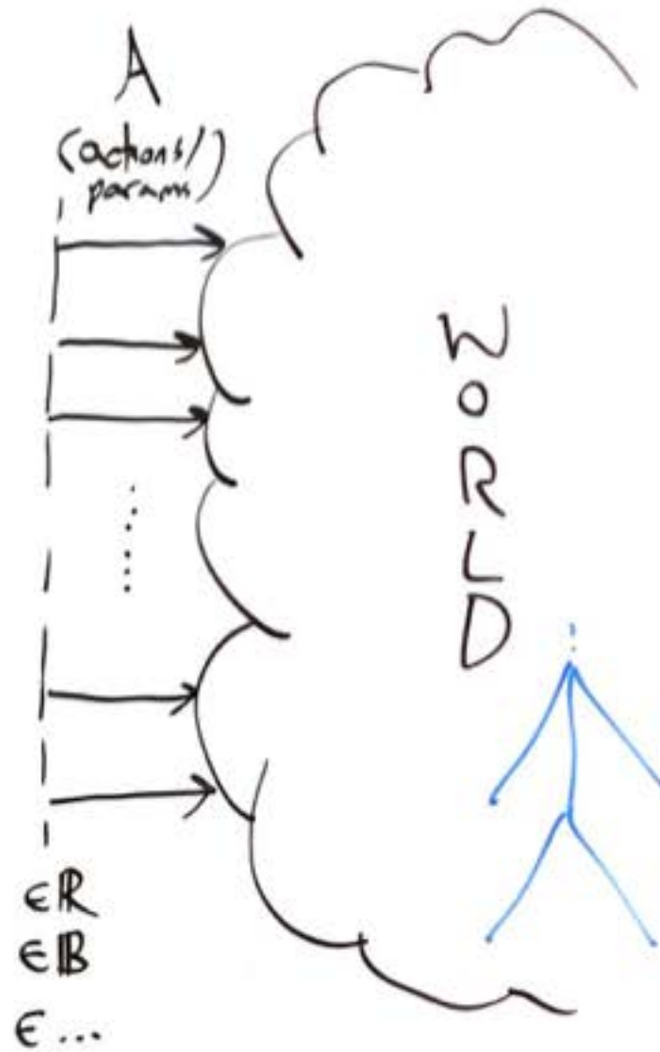

S
(signals)
WORLD
∈ ℝ
∈ 𝔹
etc.


KNOWLEDGE
GENERAL VALUE FUNCTION
Z
π
γ
X
P

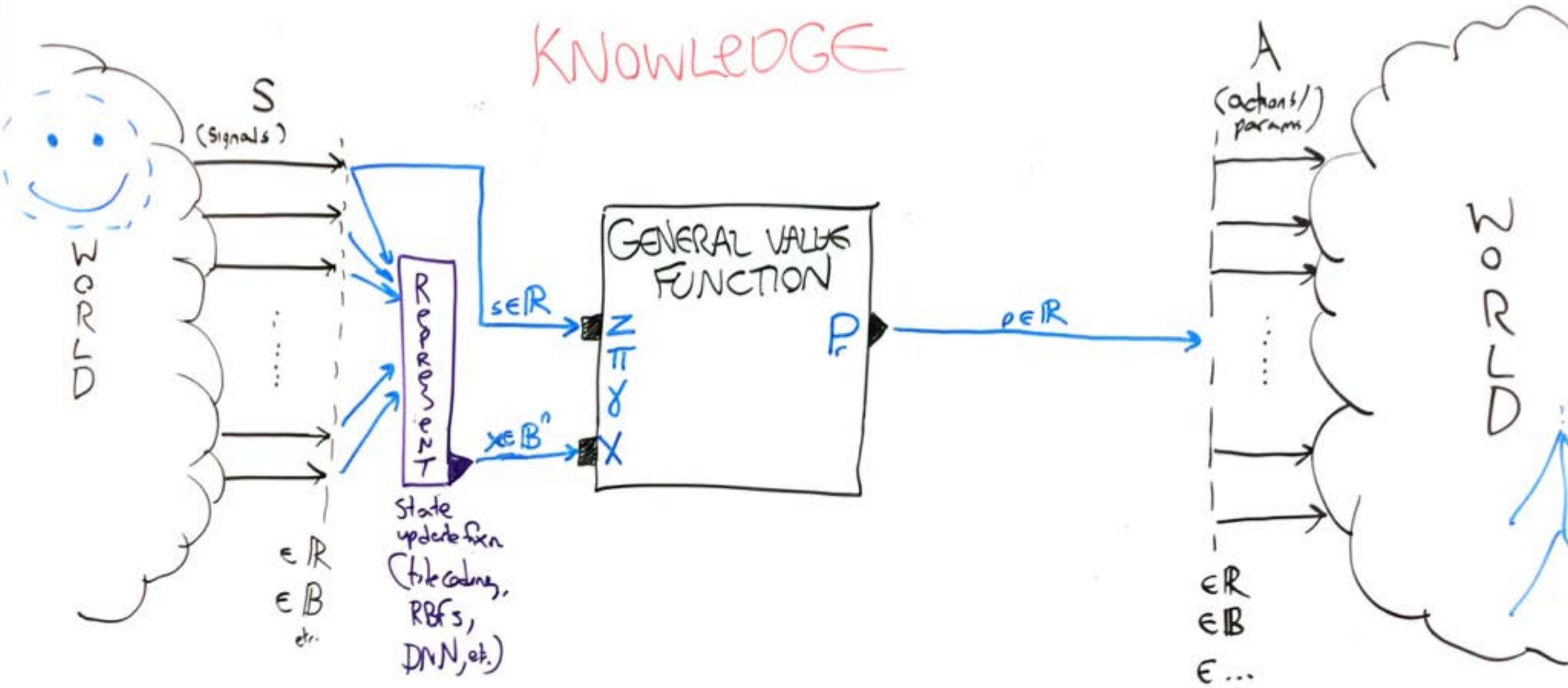

A
(actions/ params)
WORLD
∈ ℝ
∈ 𝔹
∈ ...

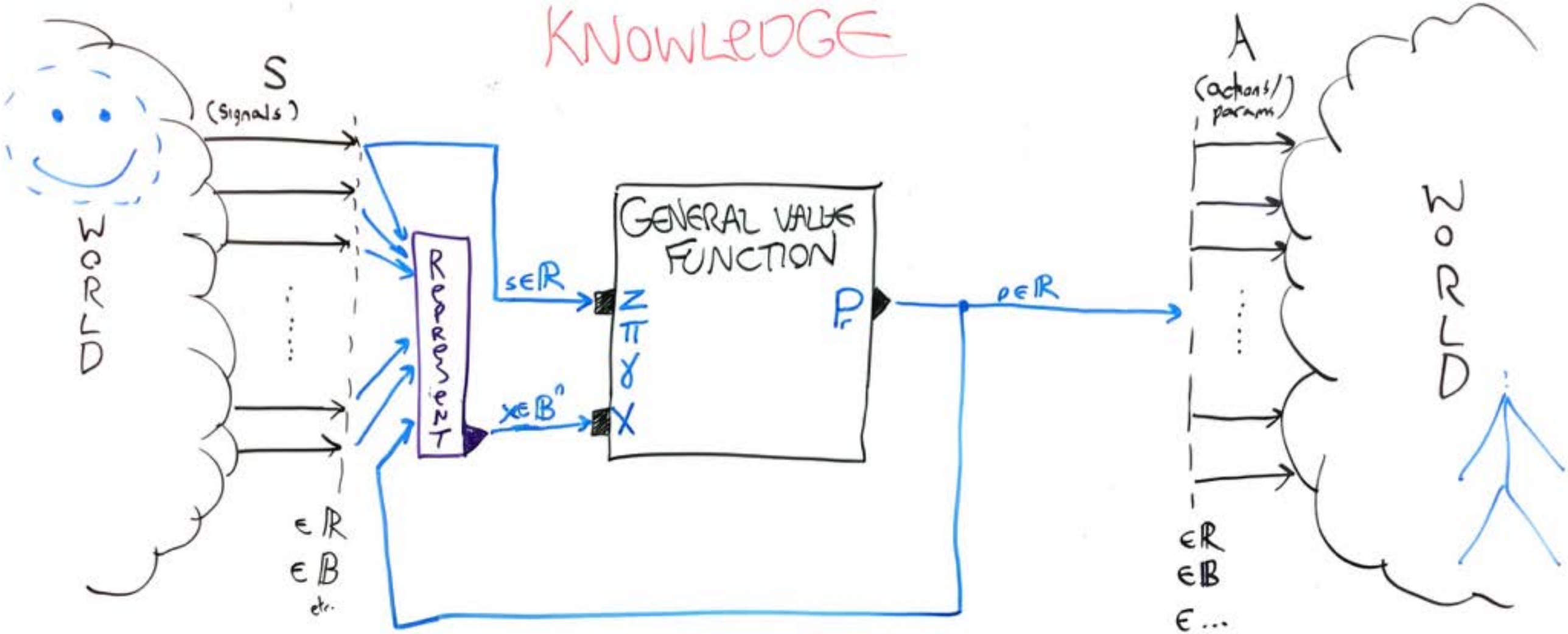

S
(signals)
WORLD
∈ ℝ
∈ 𝔹
etc.

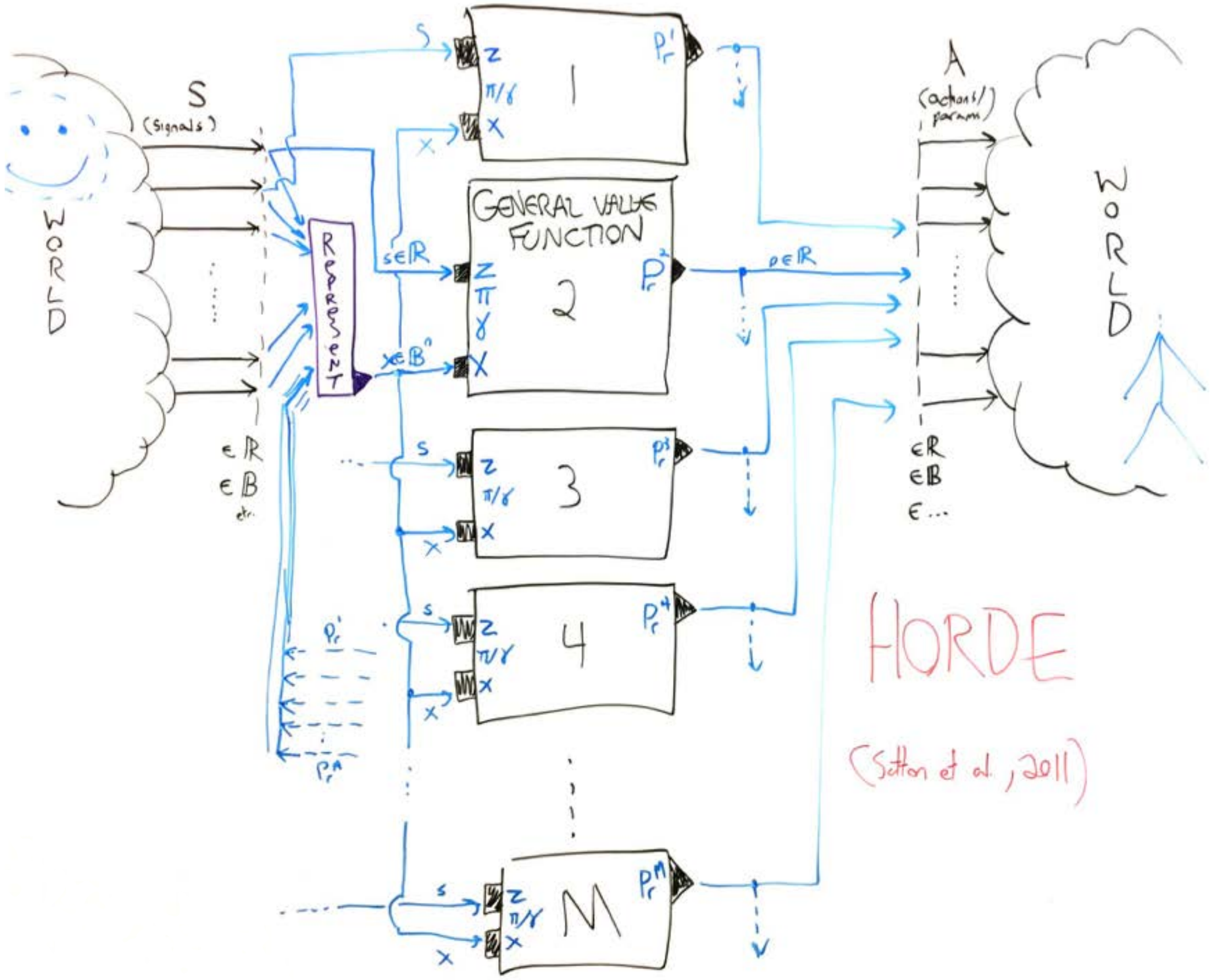

KNOWLEDGE
GENERAL VALUE FUNCTION
s∈ℝ
z
π
γ
x∈𝔹ⁿ
x
Pr
p∈ℝ

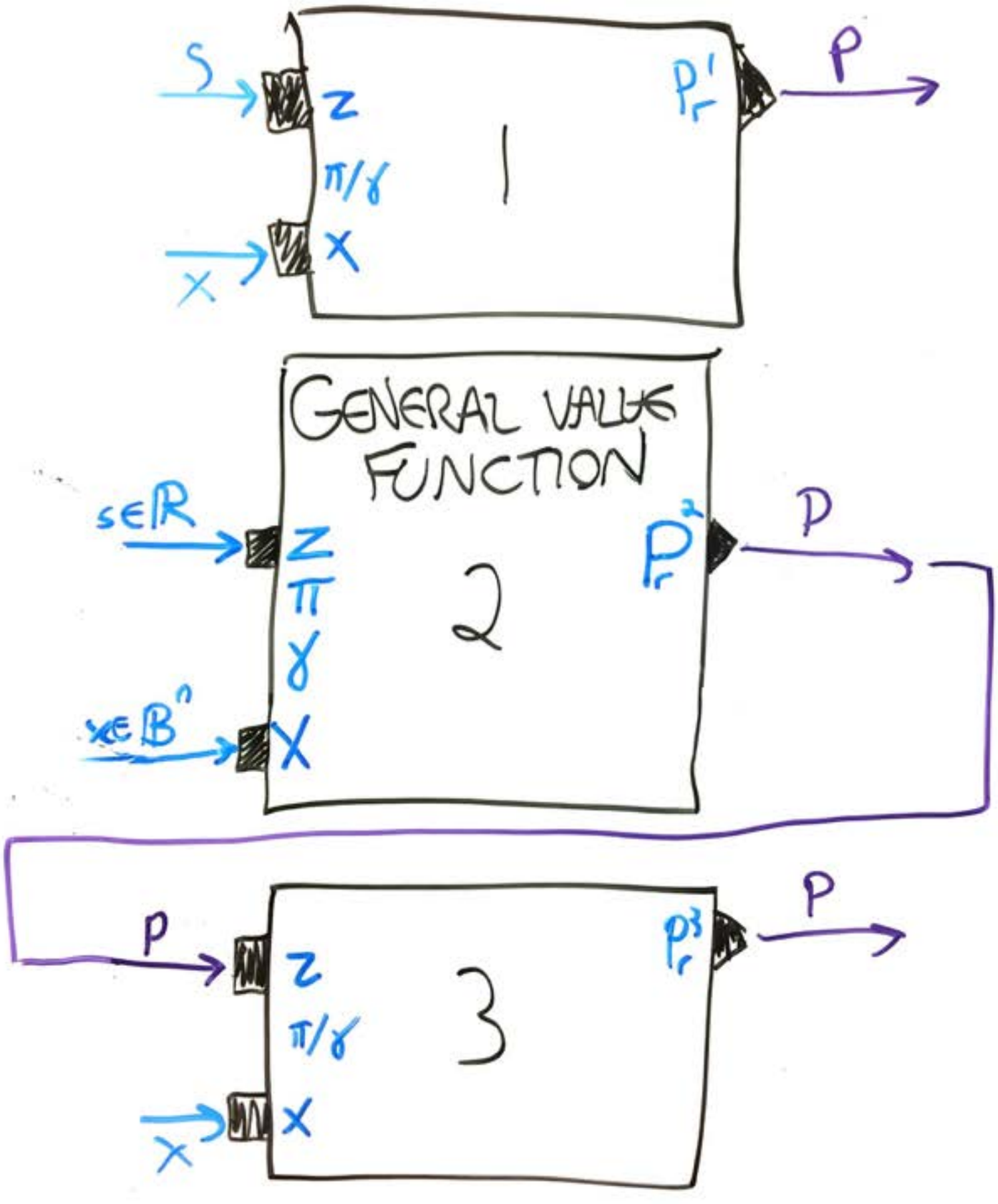

A
(actions/
params)
WORLD
∈ ℝ
∈ 𝔹
∈ ...

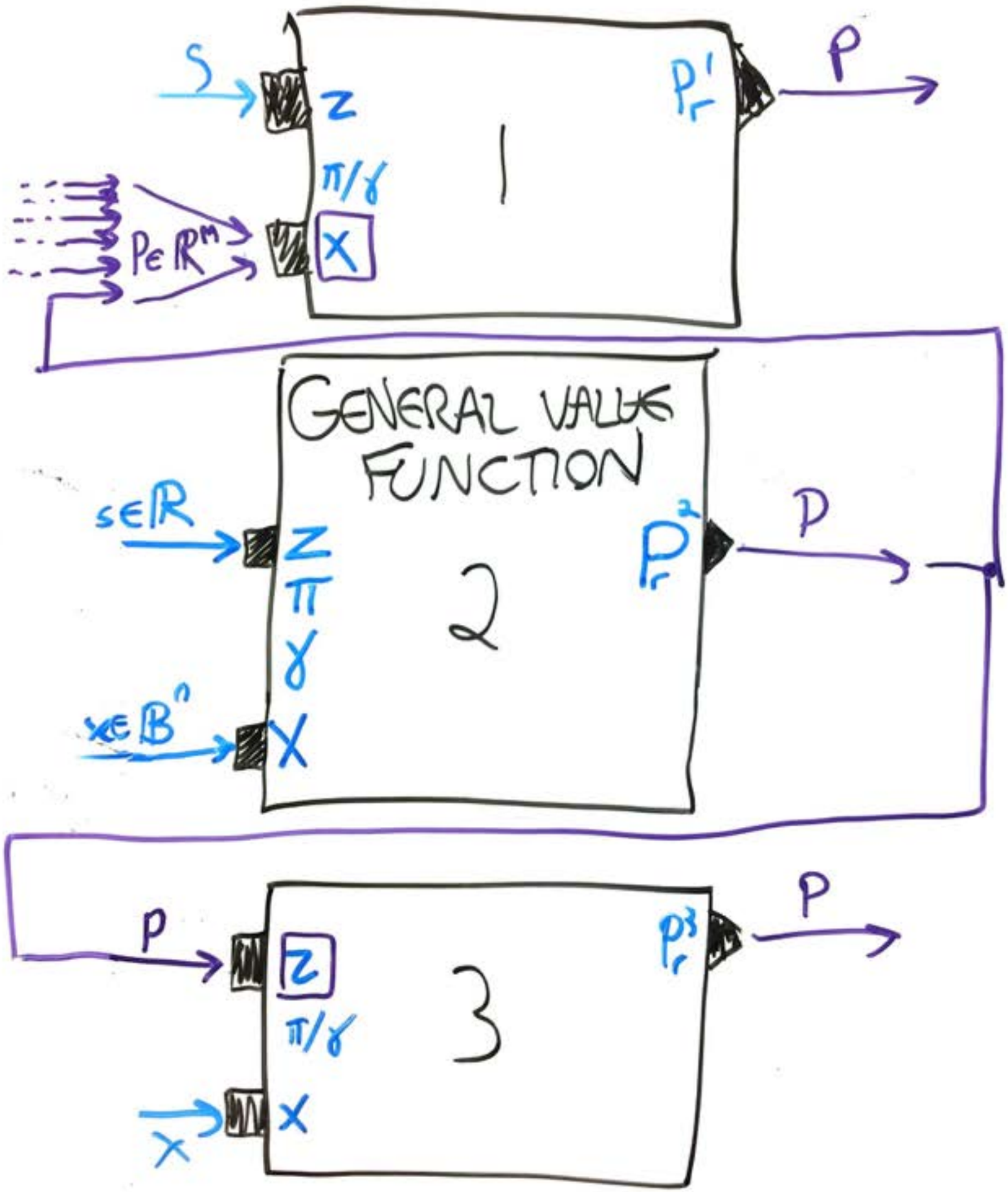
KNOWLEDGE


S
(signals)
WORLD
∈ℝ
∈𝔹
etc.
REPRESENT
State update fxn
(tile coding, RBFs, DNN, etc.)
s∈ℝ
x∈𝔹ⁿ
GENERAL VALUE FUNCTION
Z
π
γ
X
Pr
ρ∈ℝ
A
(actions/ params)
∈ℝ
∈𝔹
∈ ...
WORLD

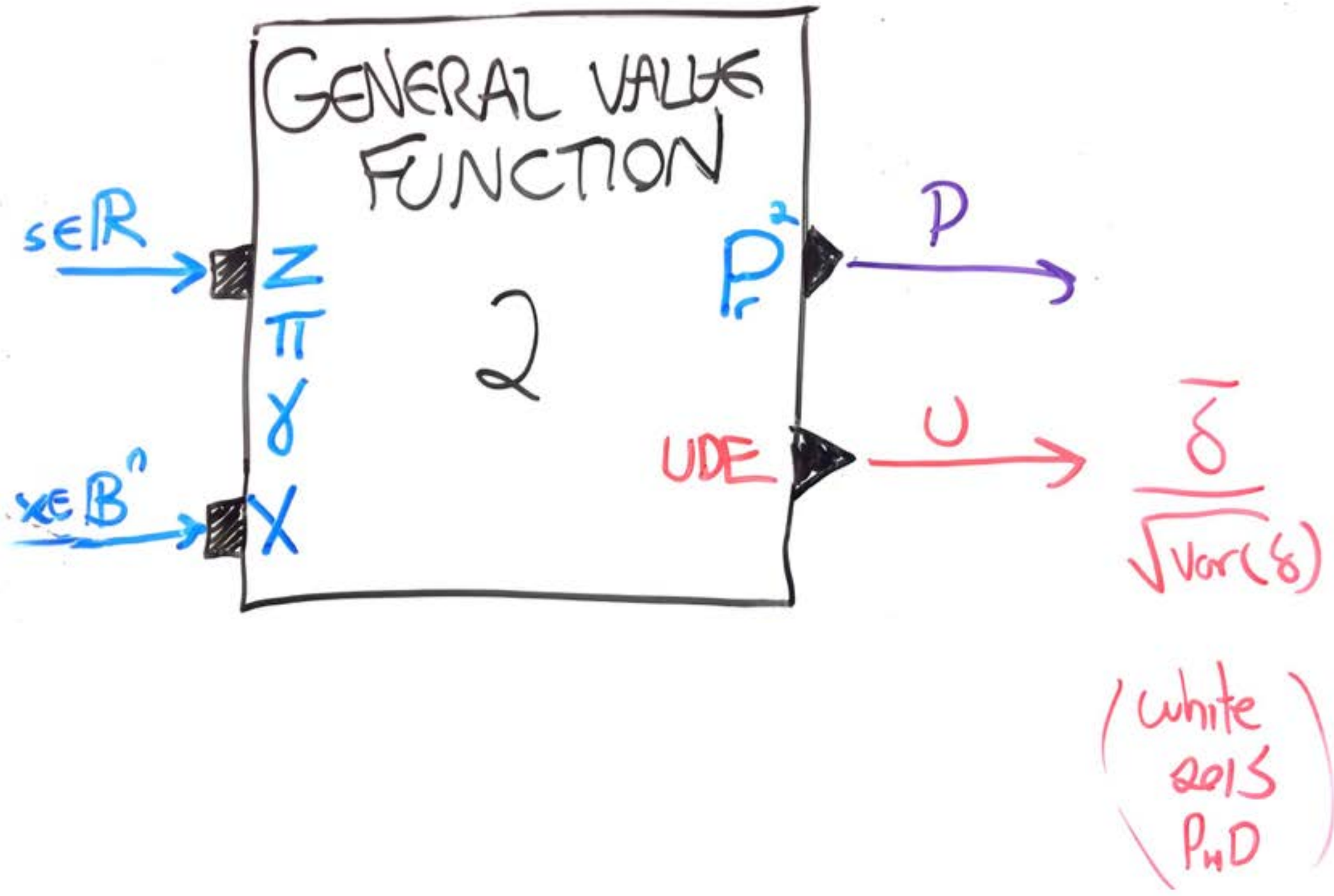

KNOWLEDGE
S
(signals)
WORLD
REPRESENT
s∈ℝ
x∈𝔹ⁿ
GENERAL VALUE FUNCTION
Z
π
γ
X
Pr
p∈ℝ
A
(actions/params)
WORLD
∈ℝ
∈𝔹
etc.
∈ℝ
∈𝔹
∈...

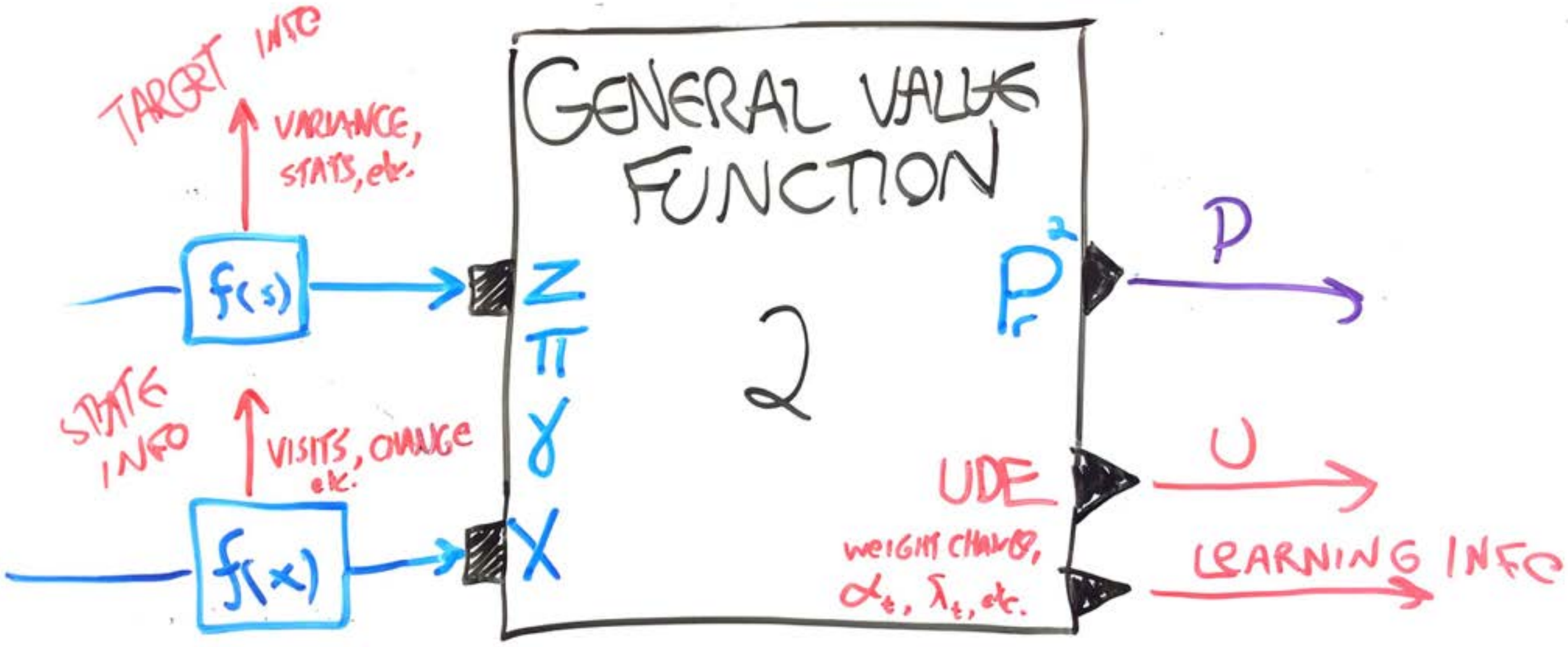

S
(Signals)
WORLD
REPRESENT
∈ ℝ
∈ 𝔹
etc.
s∈ℝ
x∈𝔹ⁿ
s
x
z
π/γ
x
1
GENERAL VALUE FUNCTION
2
3
4
M
A
(actions/ params)
WORLD
∈ℝ
∈𝔹
∈ ...
HORDE
(Sutton et al., 2011)


S
z
π/γ
x
X
1
P_r'
P
GENERAL VALUE FUNCTION
s∈R
z
π
γ
x∈Bⁿ
X
2
P_r^2
P
P
z
π/γ
x
X
3
P_r^3
P

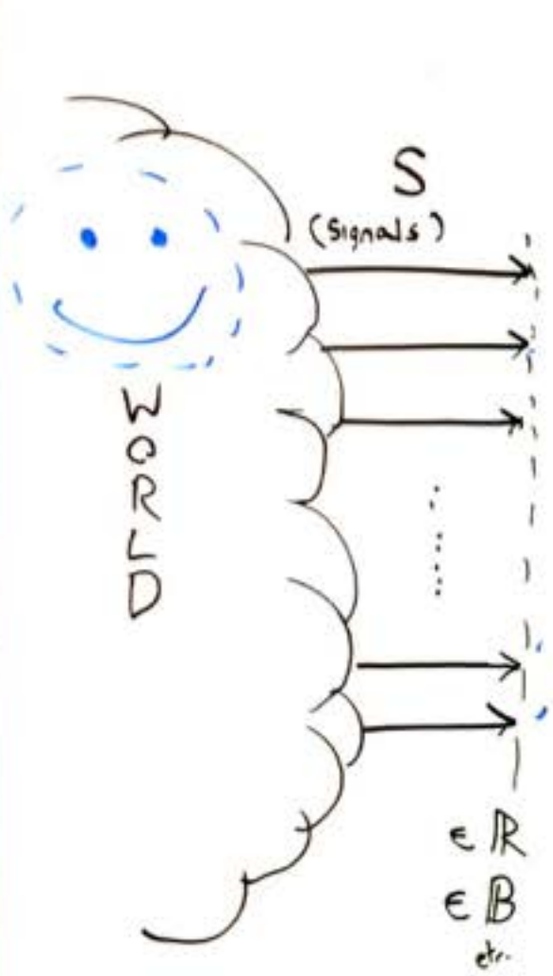


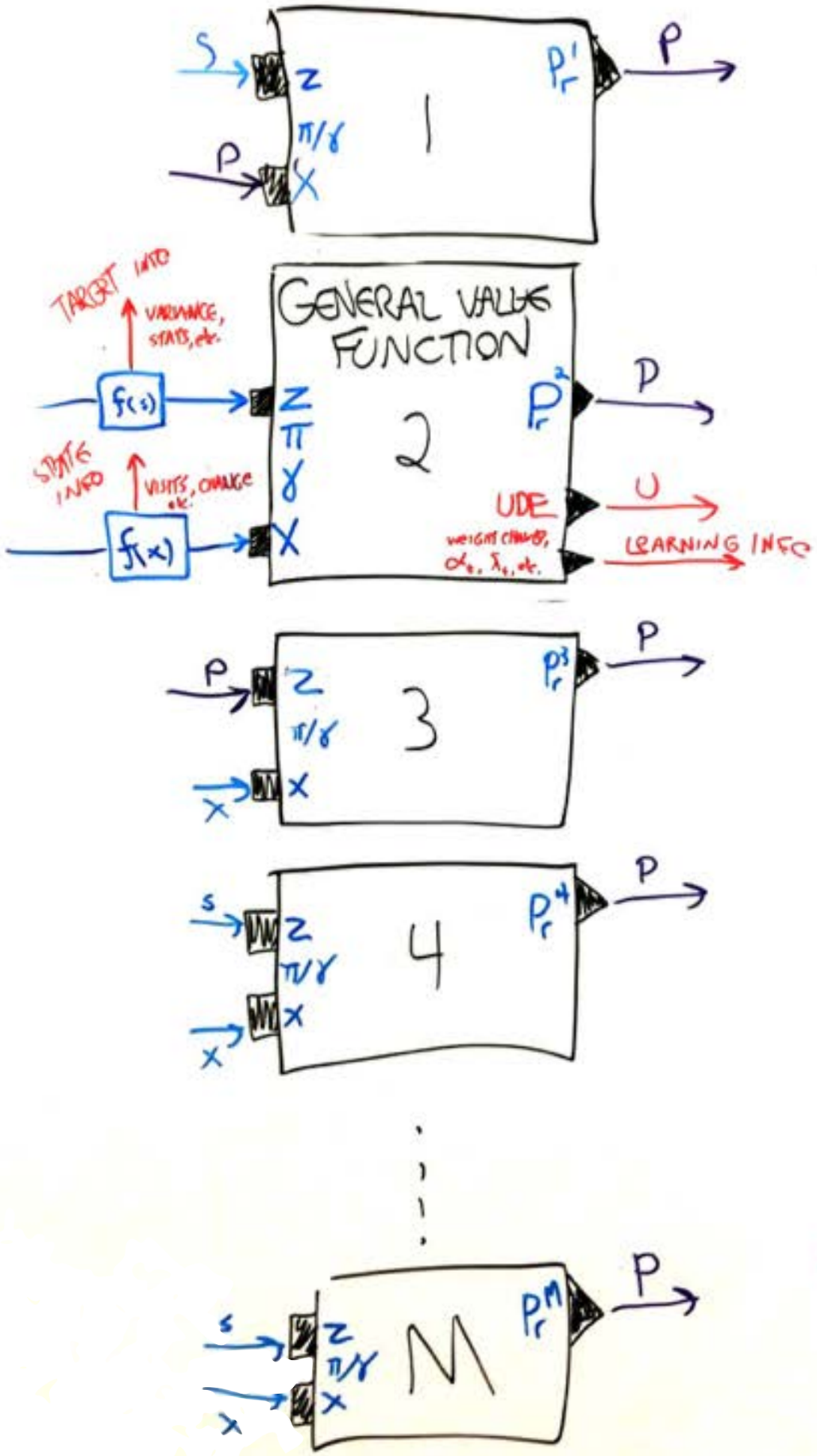
s
z
π/γ
X
P∈ℝ^m
1
P_r^1
P
GENERAL VALUE FUNCTION
s∈ℝ
z
π
γ
x∈B^n
X
2
P_r^2
P
P
z
π/γ
X
x
3
P_r^3
P

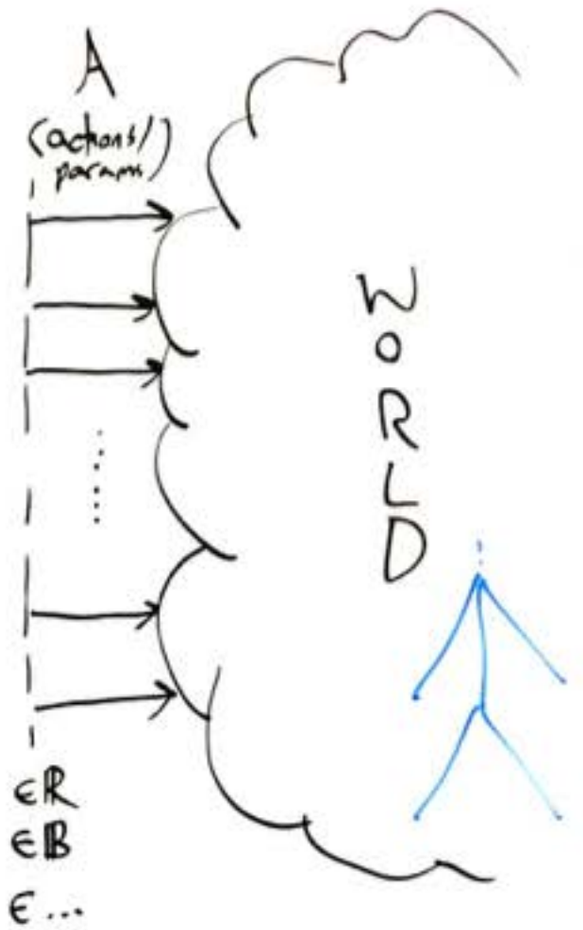

GENERAL VALUE FUNCTION
$s \in \mathbb{R}$
$x \in \mathbb{B}^n$
Z
π
γ
X
Q
P_r^2
p
UDE
U
$\frac{\delta}{\sqrt{Var(\delta)}}$
(white 2015 PhD)



Sherstan et al.
2016, AGI





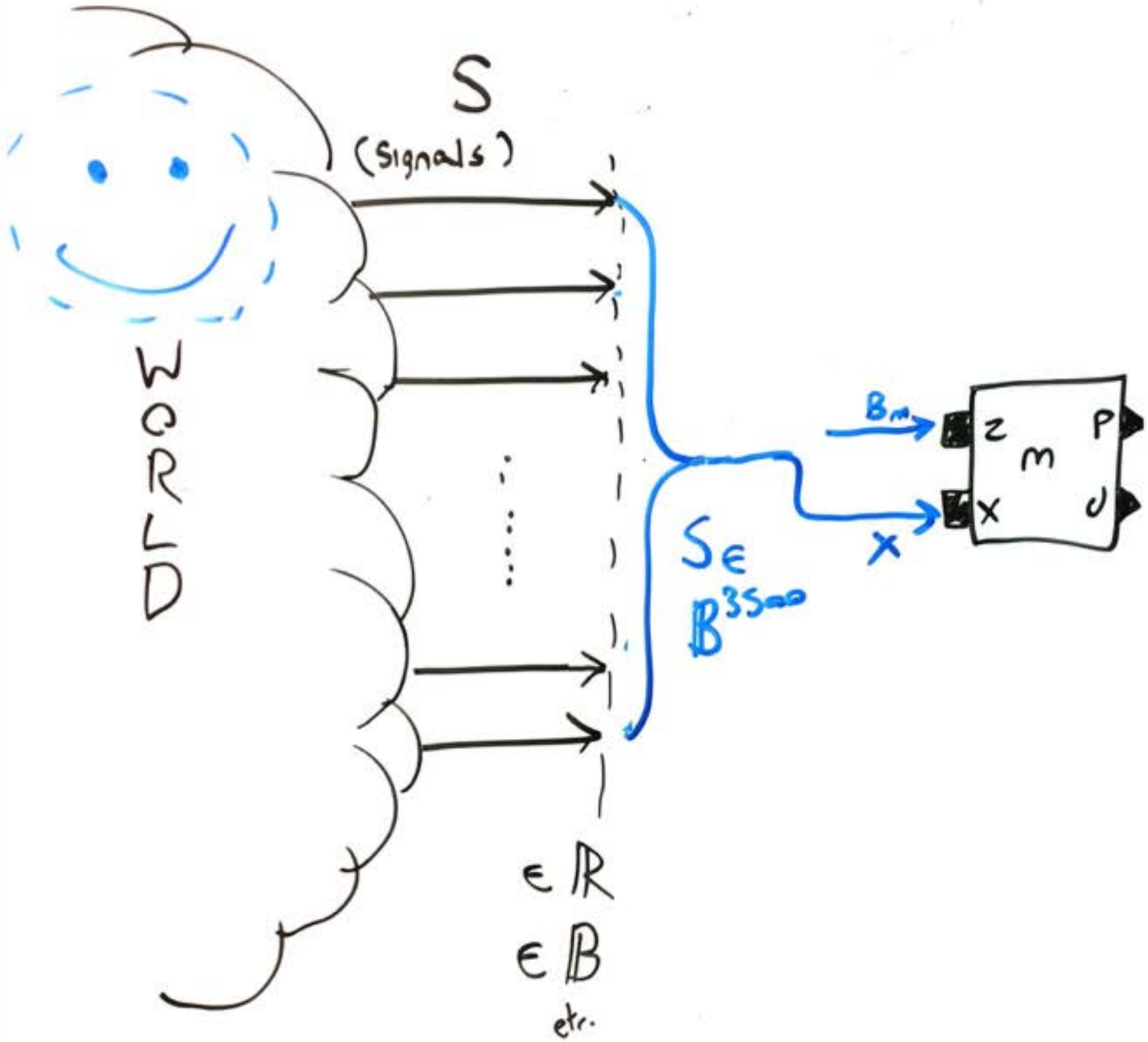


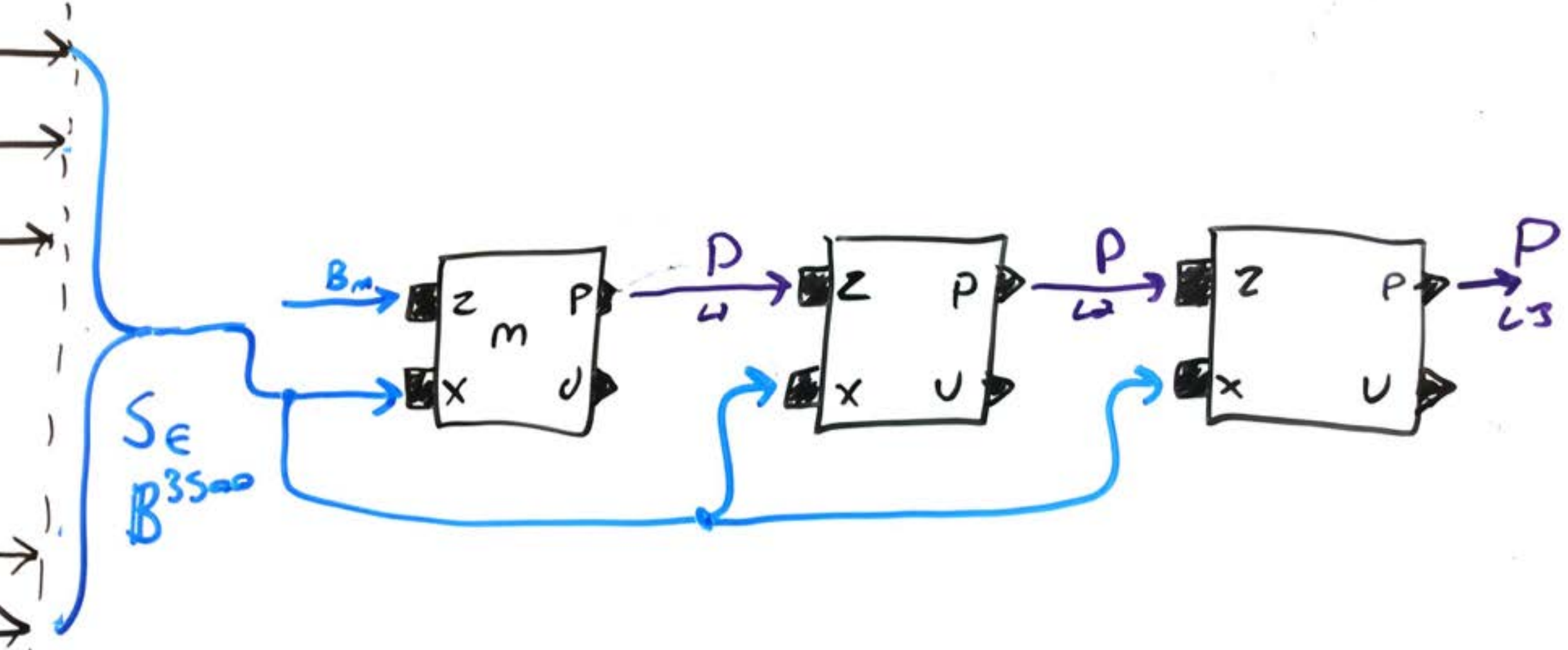
GVFs as

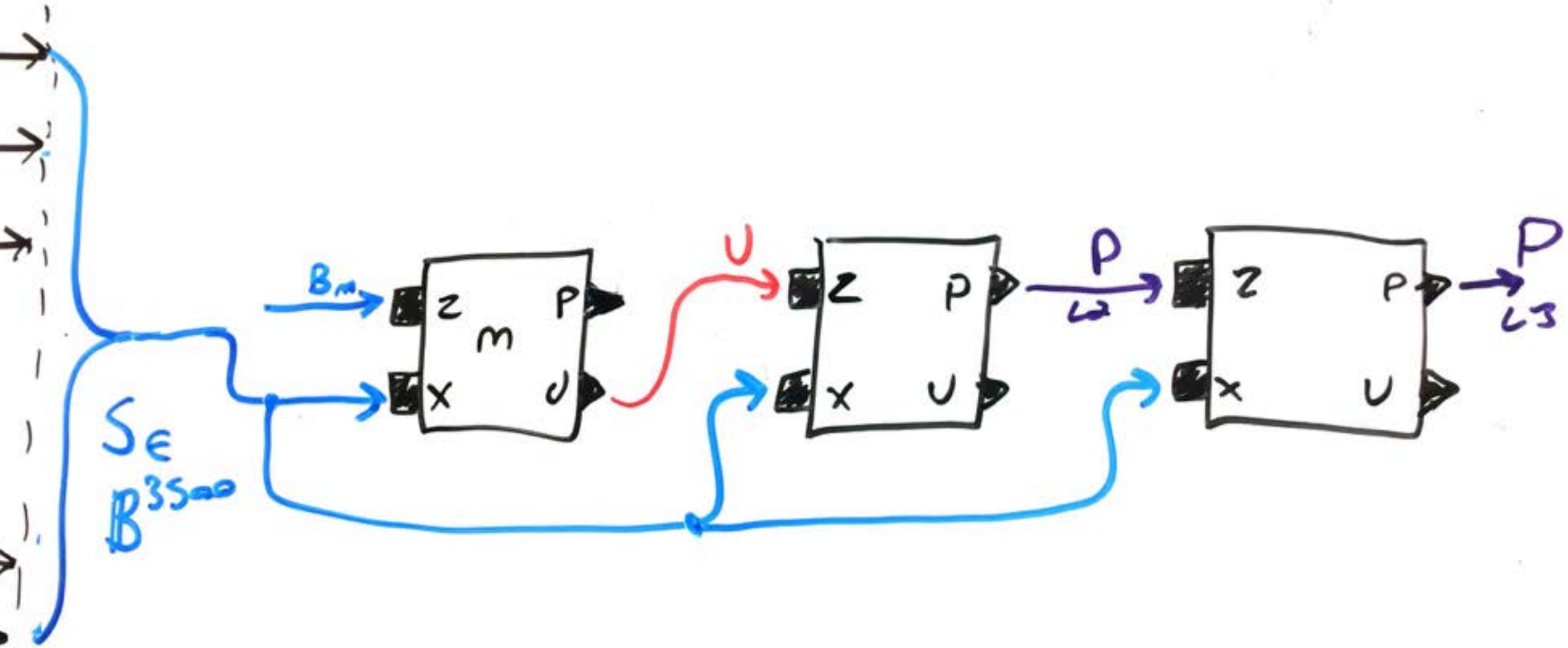
Generators

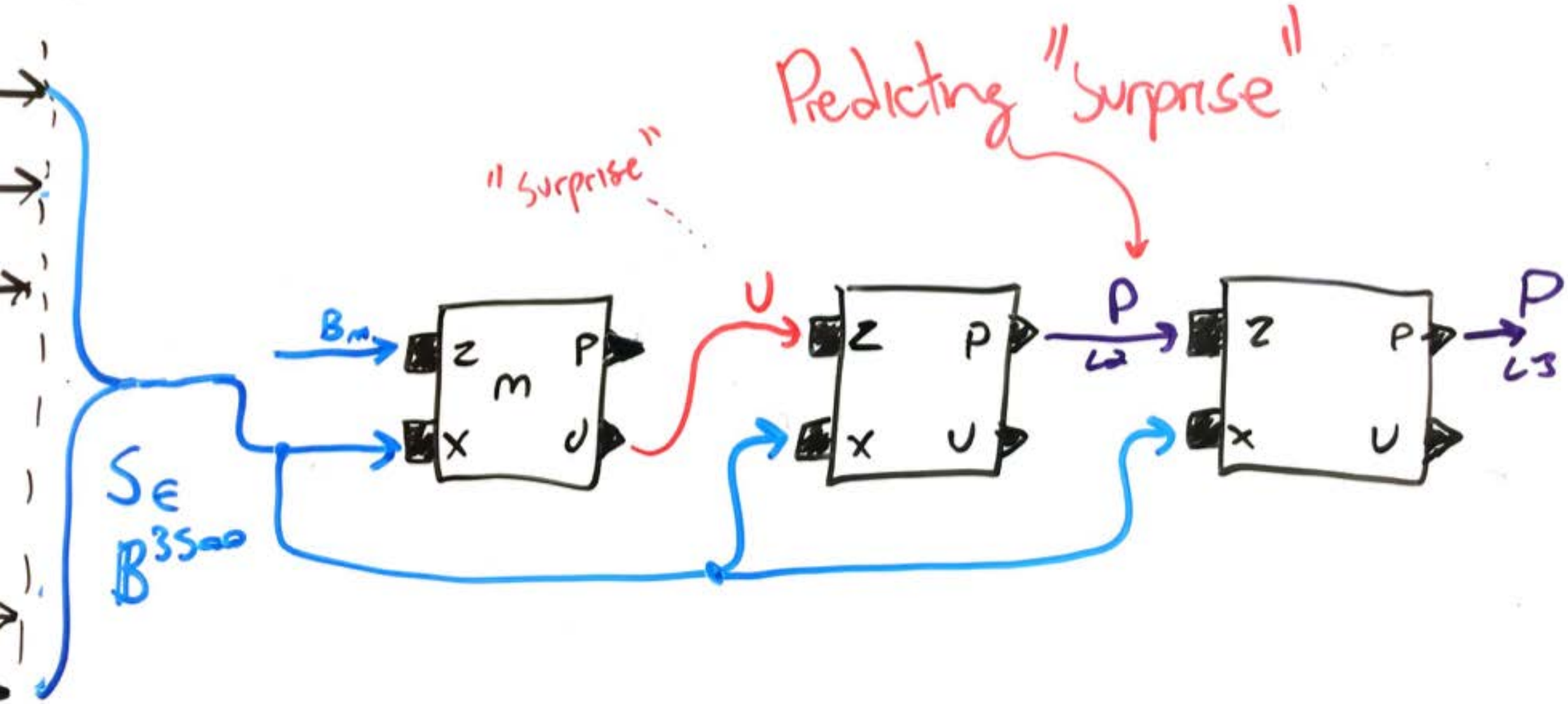
of

Sensorimotor data!

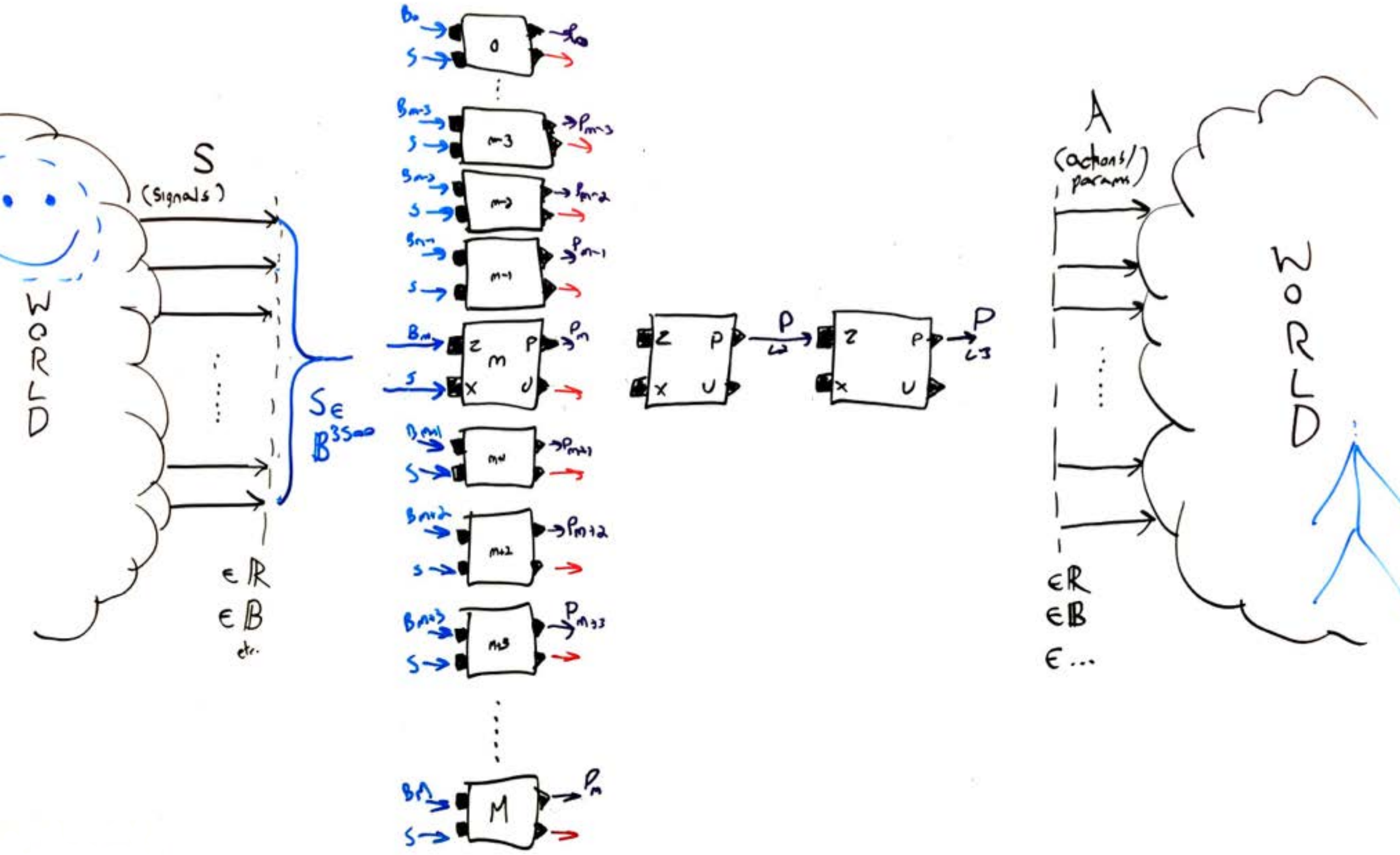

S
(signals)
WORLD
$\in \mathbb{R}$
$\in \mathbb{B}$
etc.
$S_\in$
$\mathbb{B}^{3S_\infty}$
B_m
x
z
m
p
x
u

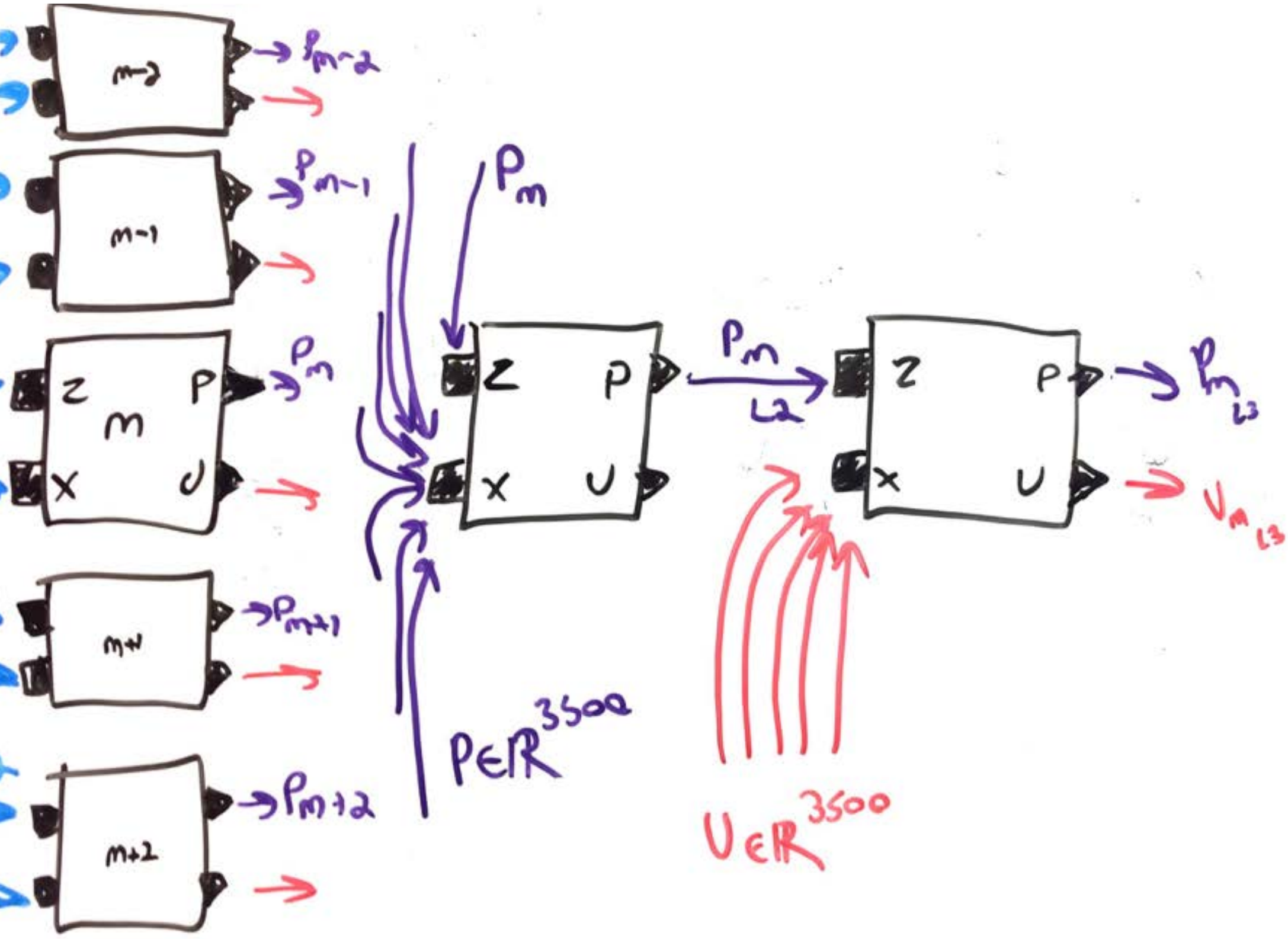

B_m
z
m
p
x
u
P
ω
z
p
x
u
P
ω
z
p
x
u
P
L_3
S_ϵ
B^{3Sab}

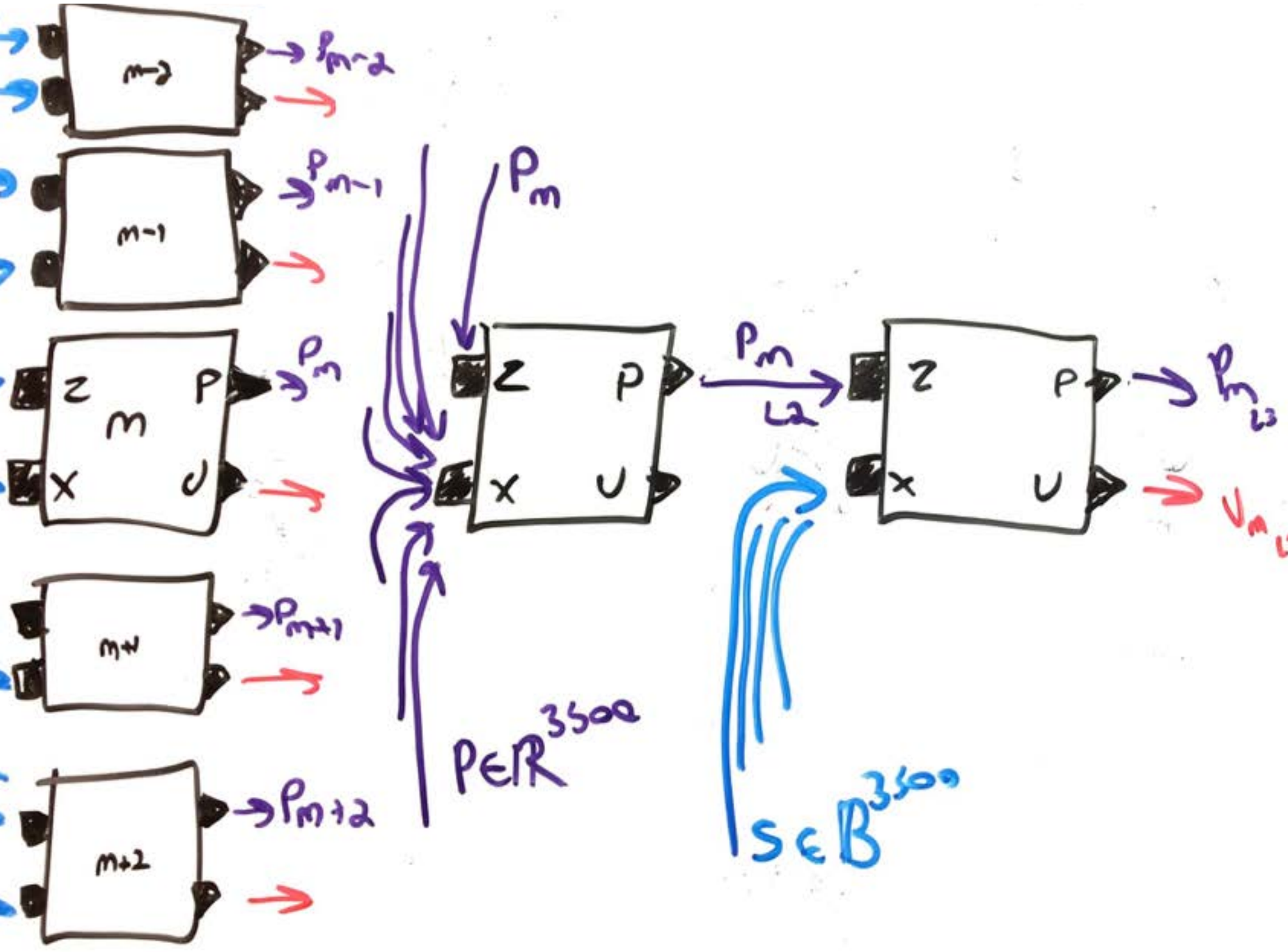

B_m
z
m
p
x
u
u
z
p
x
u
P
ω
z
p
x
u
P
L_3
S_ϵ
$B^{3S_{\infty}}$

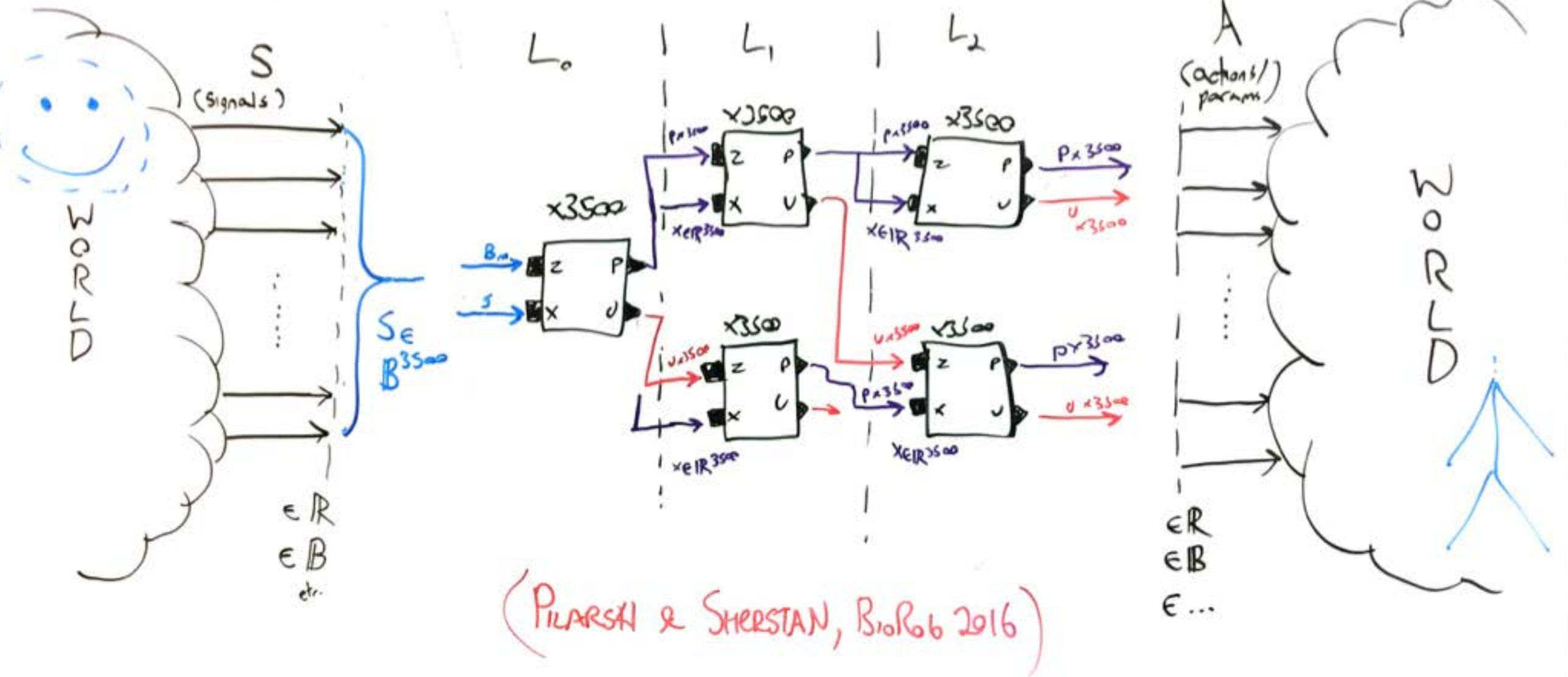


Predicting "surprise"
"surprise"
B_m
z
m
p
x
u
U
z
p
x
u
P
L_2
z
p
x
u
P
L_3
S_ϵ
$\mathbb{B}^{3S_\infty}$

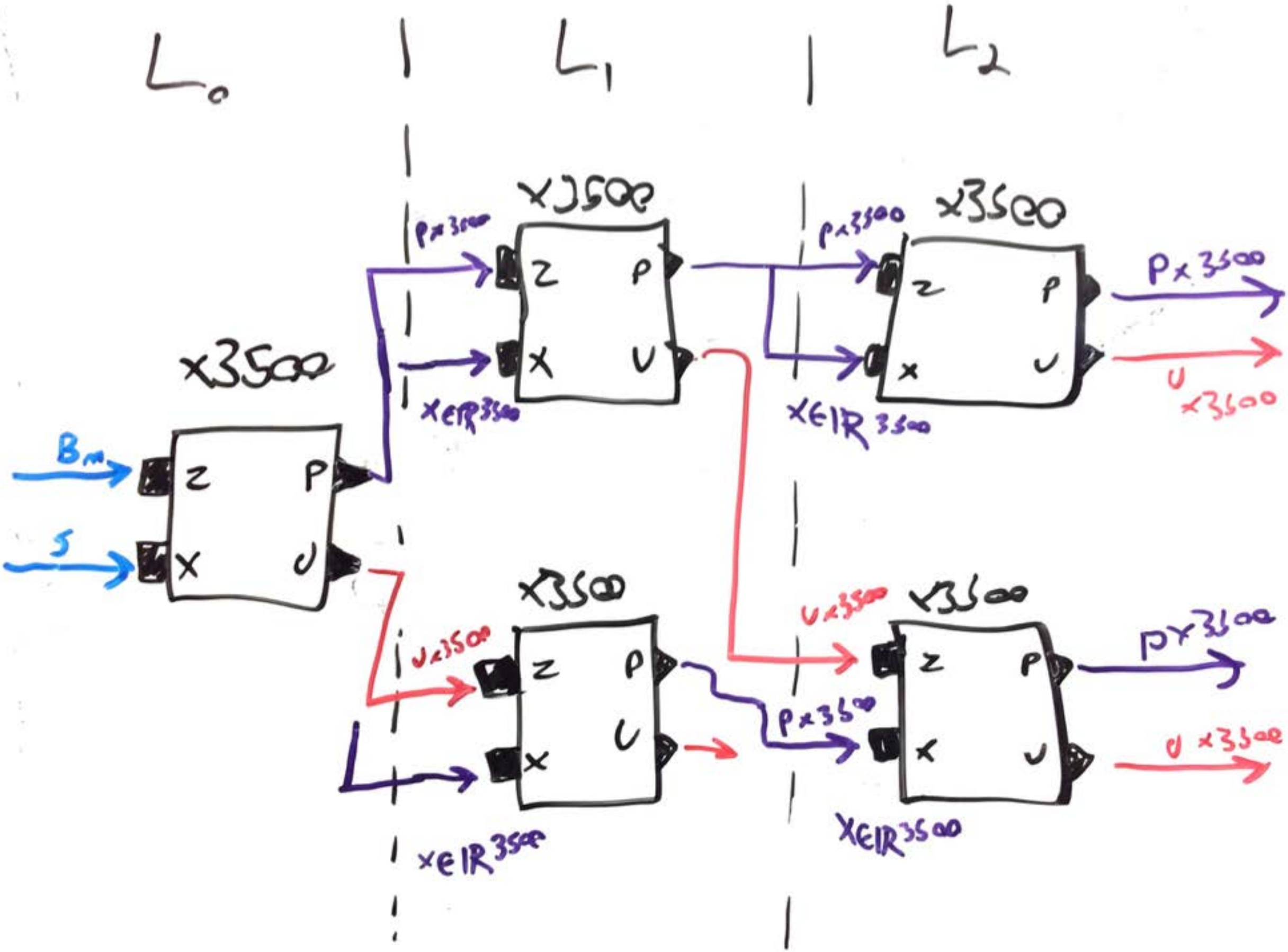

WORLD
S
(signals)
S_ϵ
$\mathbb{B}^{35000}$
$\in \mathbb{R}$
$\in \mathbb{B}$
etc.
0
m-3
m-2
m-1
m
z
x
p
u
M
A
(actions/
params)
$\in \mathbb{R}$
$\in \mathbb{B}$
$\in \ldots$


m-2
p_{m-2}
m-1
p_{m-1}
z
p
m
p_m
x
u
m+1
p_{m+1}
m+2
p_{m+2}
p_m
$p \in \mathbb{R}^{3500}$
p_m
L_2
z
p
x
u
$p_{m_{L3}}$
$u_{m_{L3}}$
$u \in \mathbb{R}^{3500}$

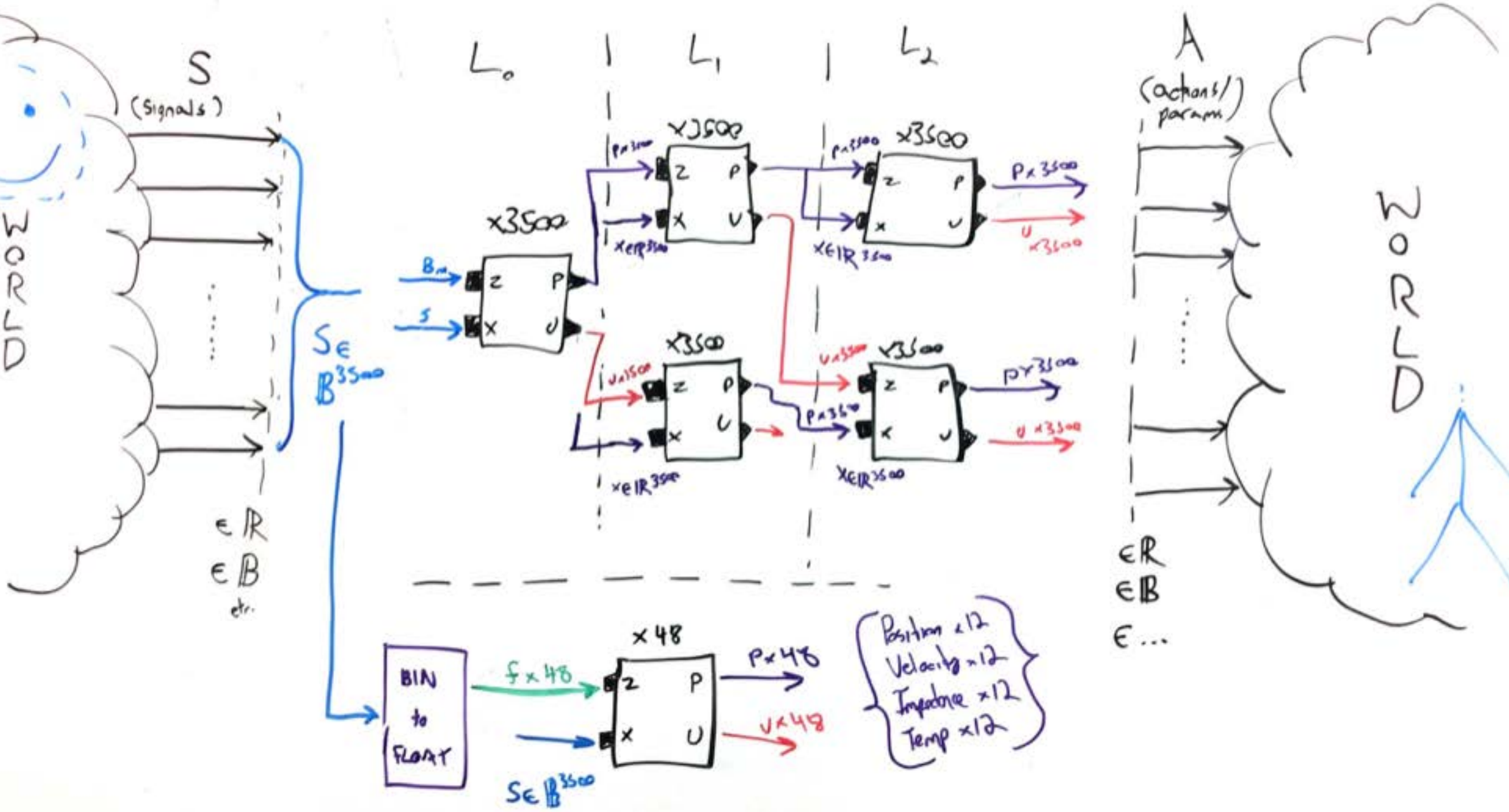

m-2
p_{m-2}
m-1
p_{m-1}
m
z
p
x
u
p_m
m+1
p_{m+1}
m+2
p_{m+2}
p_m
$p \in \mathbb{R}^{3500}$
p_m
L2
z
p
x
u
$p_{m_{L3}}$
$V_{m_{L3}}$
$s \in \mathbb{B}^{3500}$



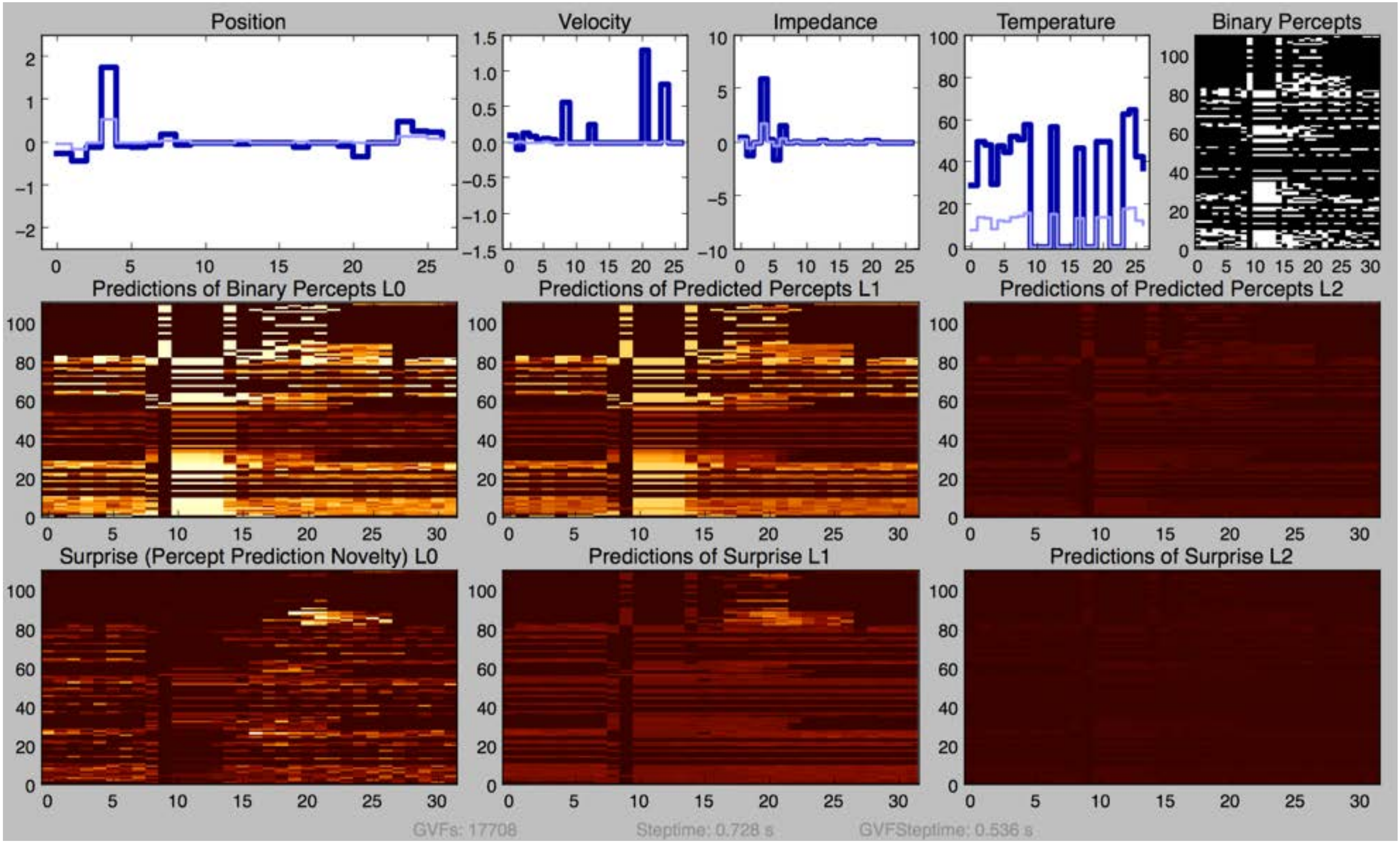
(PILARSKI & SHERSTAN, BioRob 2016)



L0
L1
L2
x3500
x3500
x3500
x3500
x3500
Bm
S
z
p
x
u
p×3500
x∈IR3500
u×3500
x∈IR3500
p×3500
x∈IR3500
p×3500
u×3500
p×3500
u×3500
x∈IR3500

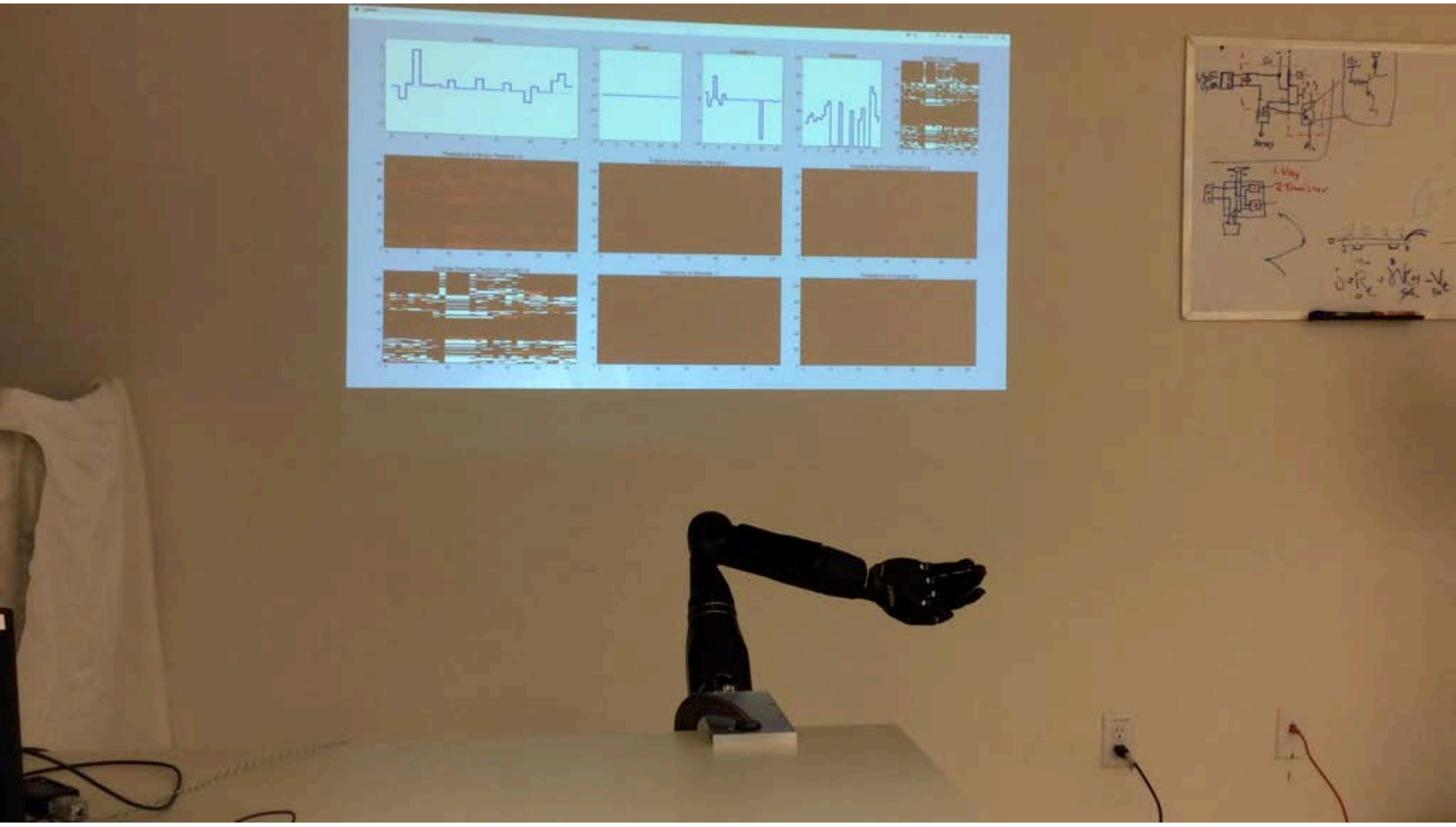


S
(signals)
WORLD
$\in \mathbb{R}$
$\in \mathbb{B}$
etc.
$S \in \mathbb{B}^{3500}$
L_0
L_1
L_2
x3500
B_m
s
z
p
x
u
$p \times 3500$
$x \in \mathbb{R}^{3500}$
$u \times 3500$
A
(actions/params)
$\in \mathbb{R}$
$\in \mathbb{B}$
$\in \ldots$
BIN to FLOAT
$f \times 48$
$\times 48$
$p \times 48$
$u \times 48$
$S \in \mathbb{B}^{3500}$
Position x12
Velocity x12
Impedance x12
Temp x12



Horde on the MPL data stream: ~18k GVFs

Pilarski and Sherstan, *BioRob, 2016.*



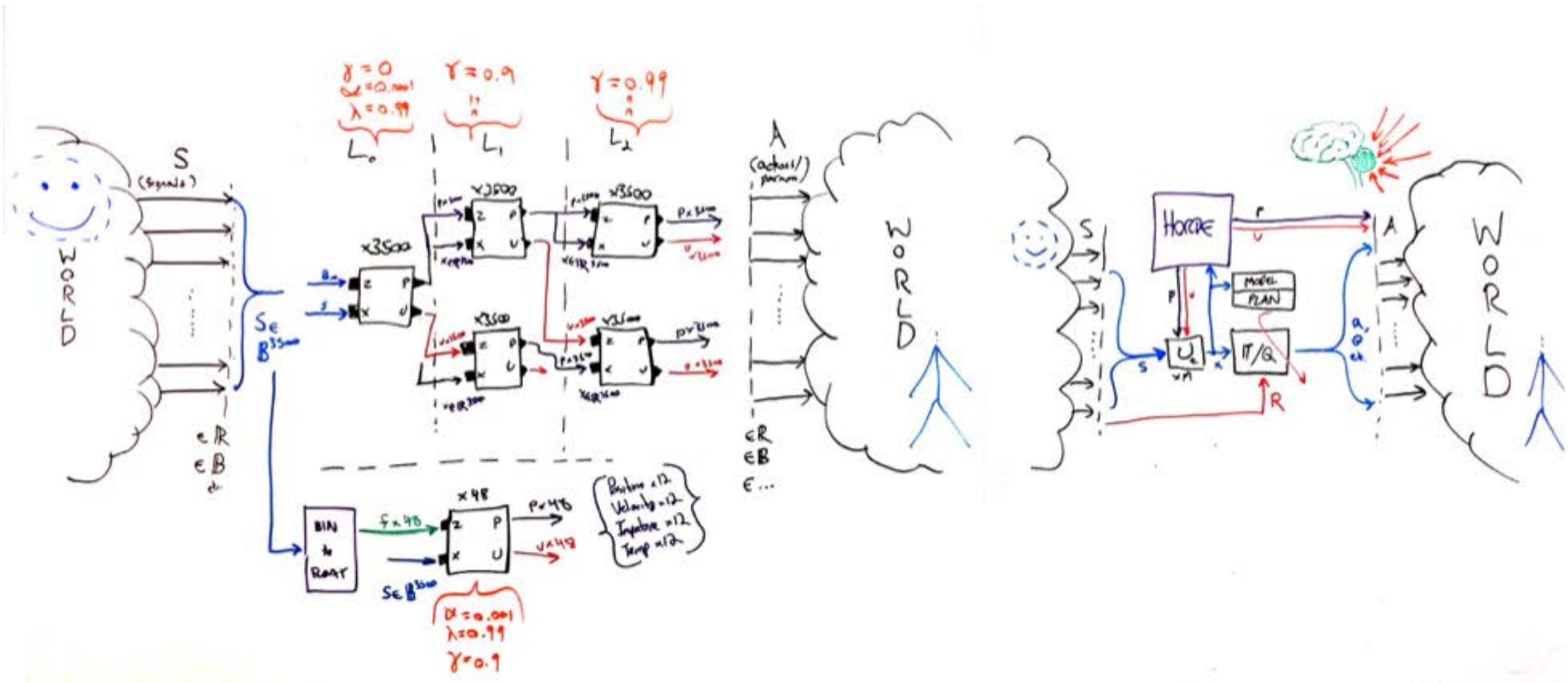
Pilarski Lab, Feb. 25, 2016
(Pilarski and Sherstan, *BioRob, 2016*)

Next steps:

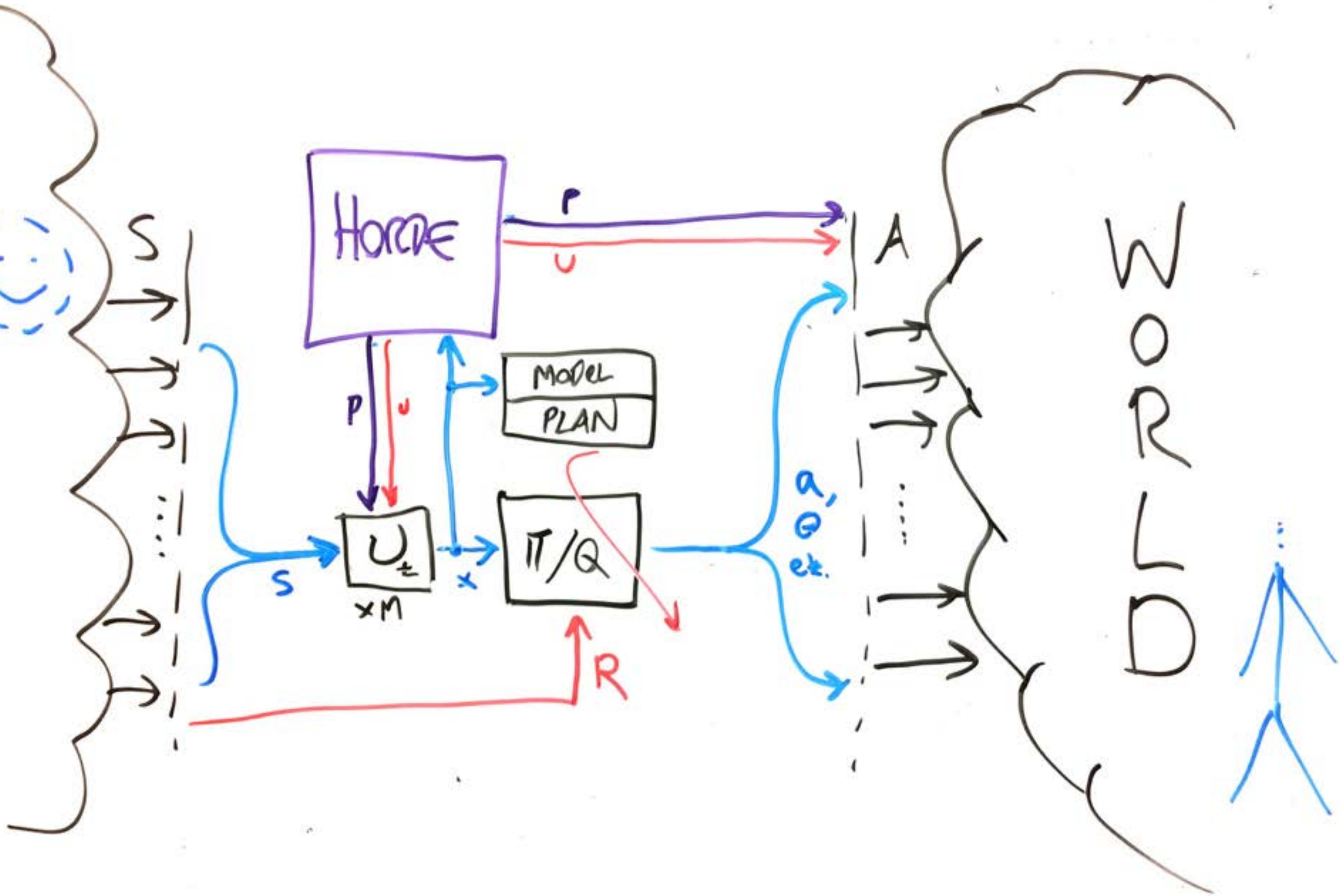
Scaling up computation to scale up Horde. (2x14core CPU, 2xTeslaK40 GPU, 128GB RAM, 40TB storage, …)

Target: 1 billion predictions a second.

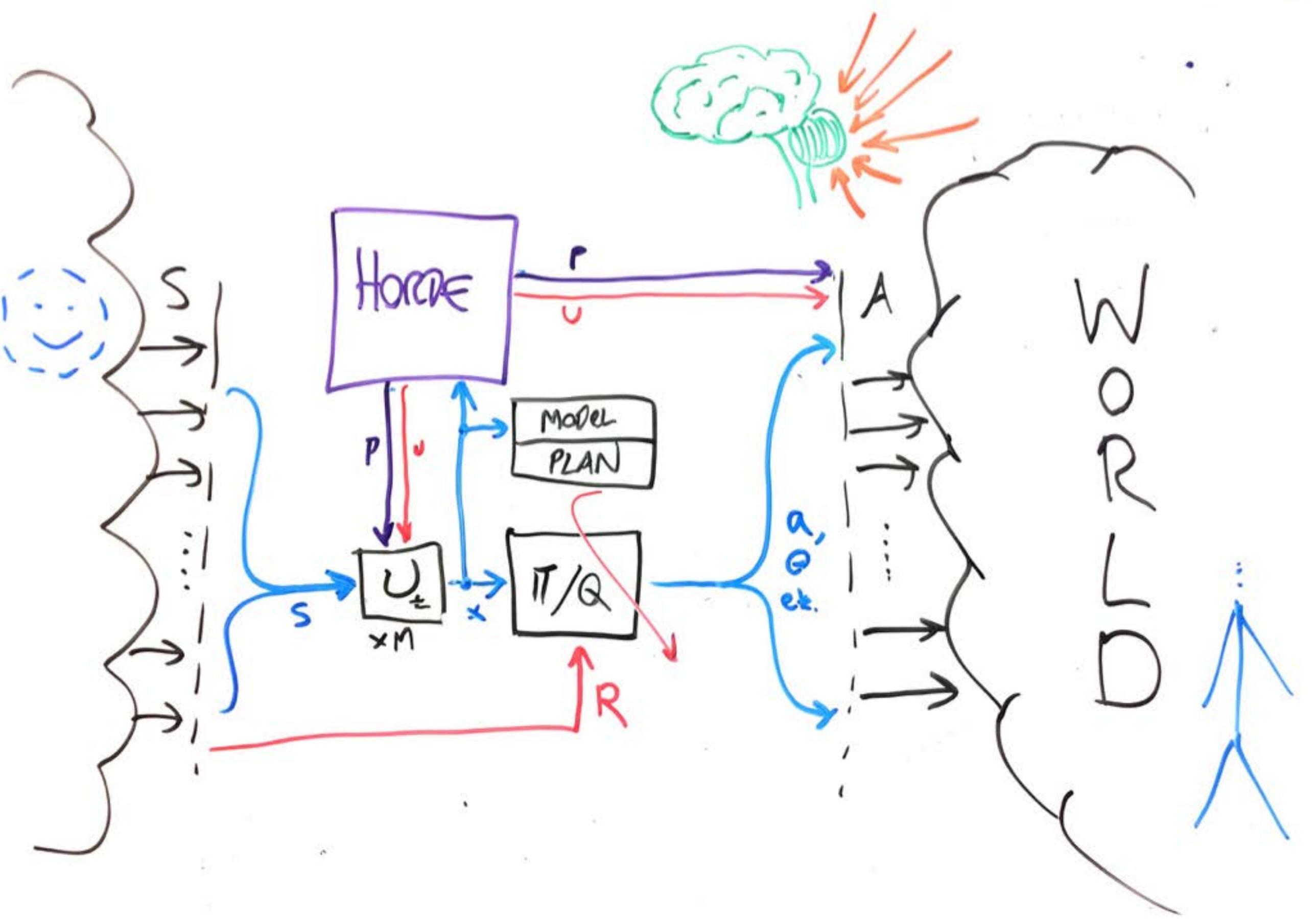
More efficient code, better computer, **representation learning** via adaptive random representations (via Sutton 1993).



WORLD
S
(signals)
$S \in \mathbb{B}^{3500}$
$\in \mathbb{R}$
$\in \mathbb{B}$
$\gamma = 0$
$\alpha = 0.001$
$\lambda = 0.99$
L_0
$\gamma = 0.9$
L_1
$\gamma = 0.99$
L_2
x3500
BIN to FLOAT
f x 48
x 48
p x 48
u x 48
$S \in \mathbb{B}^{3500}$
$\alpha = 0.001$
$\lambda = 0.99$
$\gamma = 0.9$
Positive x12
Velocity x12
Impulse x12
Temp x12
A
(actions/parameters)
$\in \mathbb{R}$
$\in \mathbb{B}$
$\in \ldots$
WORLD
S
HORDE
MODEL
PLAN
π/Q
R
A
WORLD



S
HORDE
p
u
A
WORLD
MODEL
PLAN
p
u
U_t
×M
s
x
π/Q
R
a,
θ
etc.



S
HORDE
p
u
A
WORLD
MODEL
PLAN
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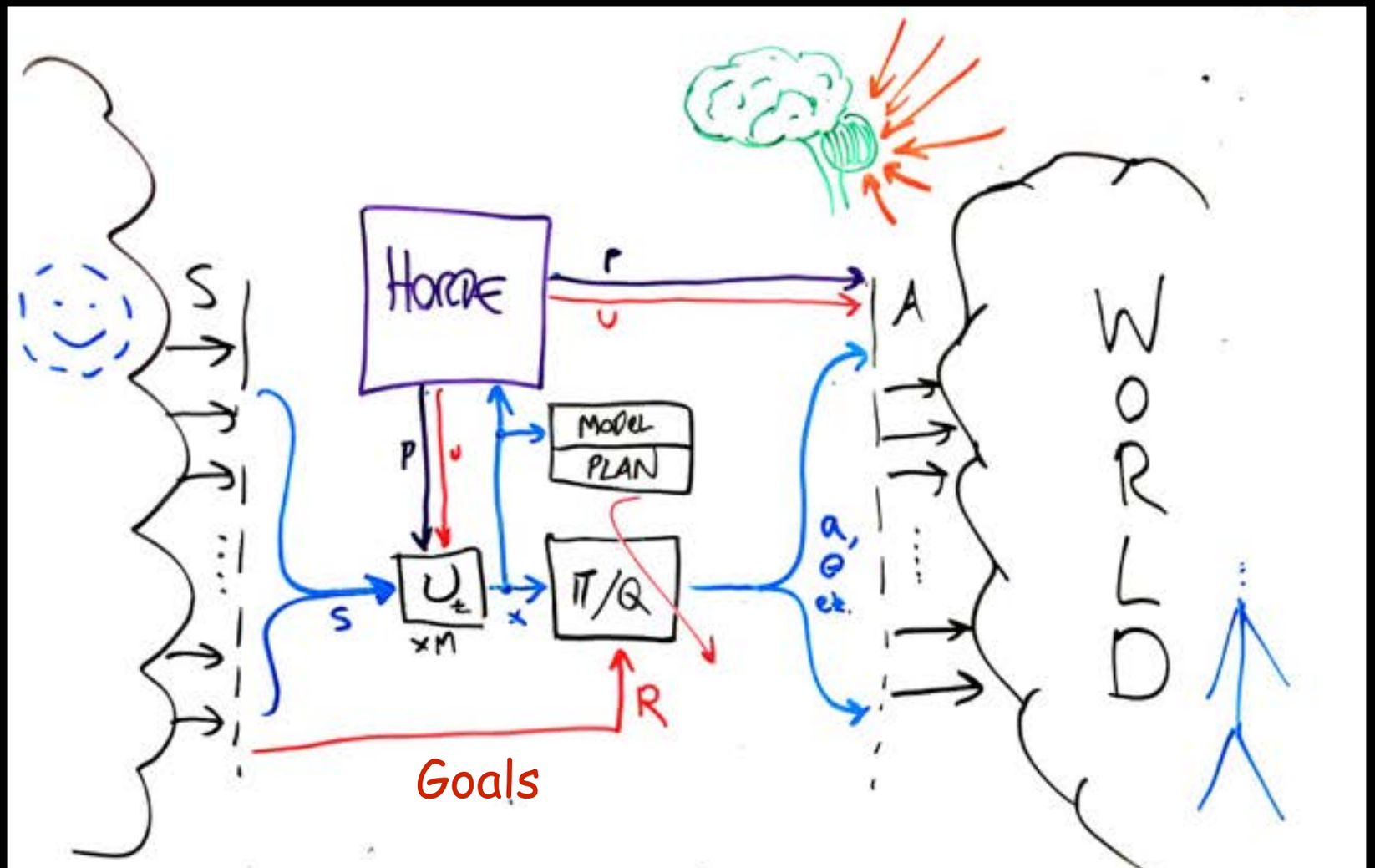
u
U_t
×M
s
x
π/Q
R
a, θ etc.



- Representation ($U_t \times M$)
- Prediction (Horde)
- Policy (π/Q)
- Models, Planning
- Intentions (?)
- Cute pictures of cats (?)
  (and dogs!)