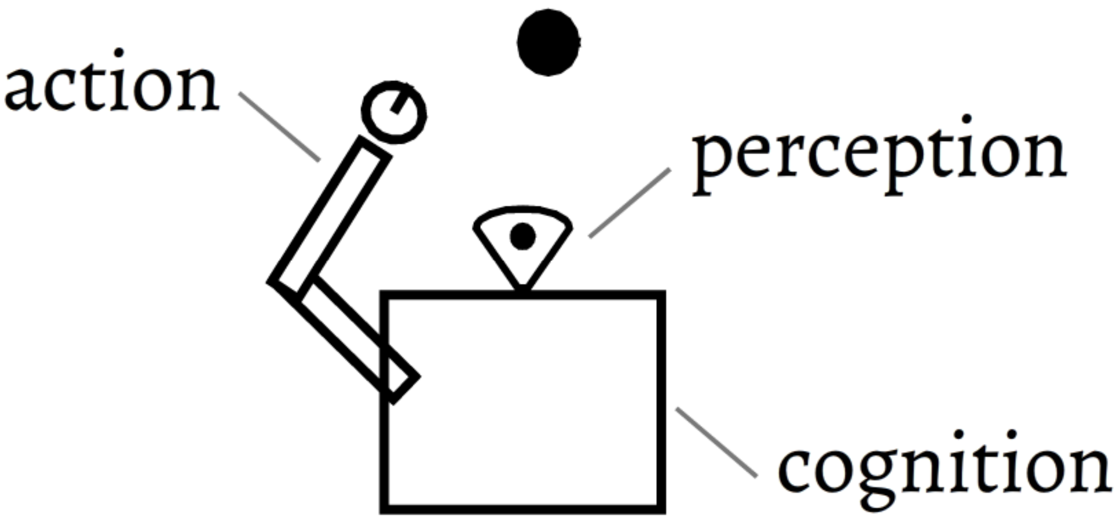
A neural dynamic architecture to generate arm movements directed at objects

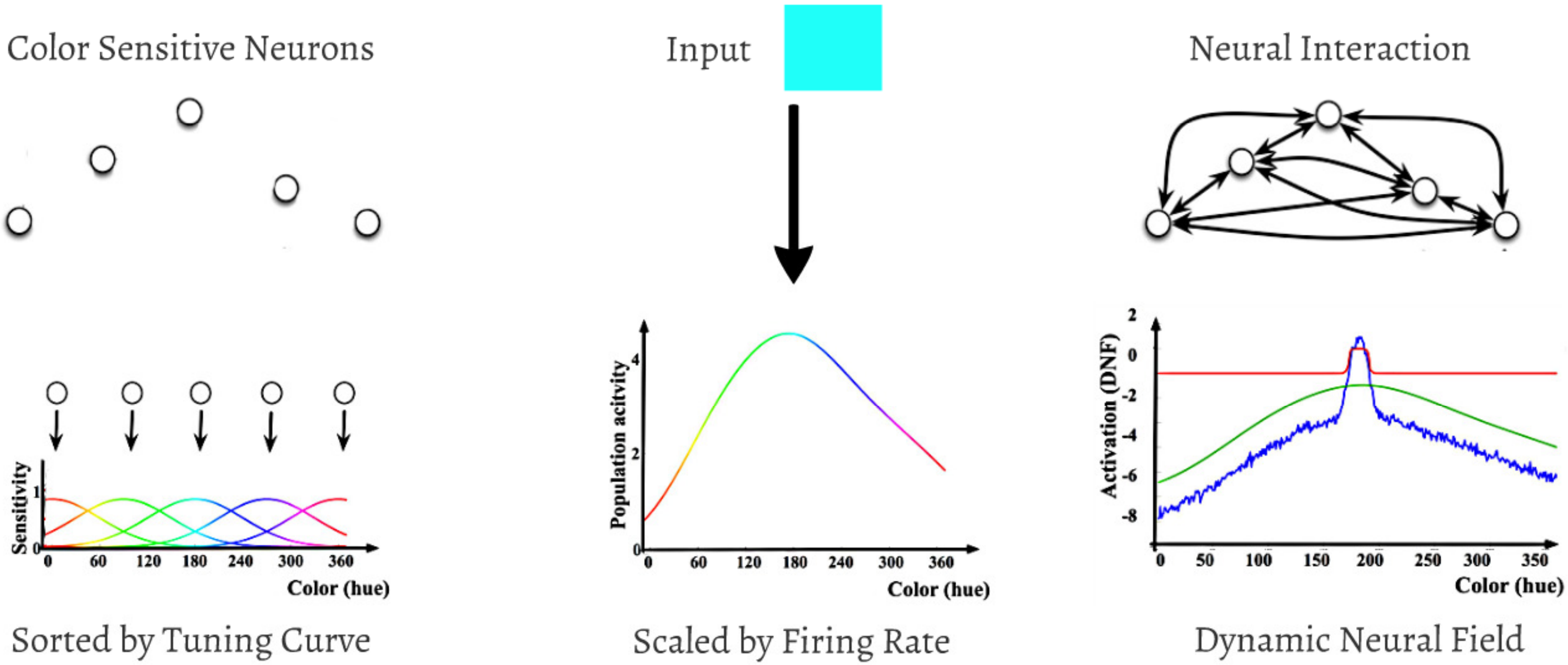
19.07.2018

Jan Tekülve

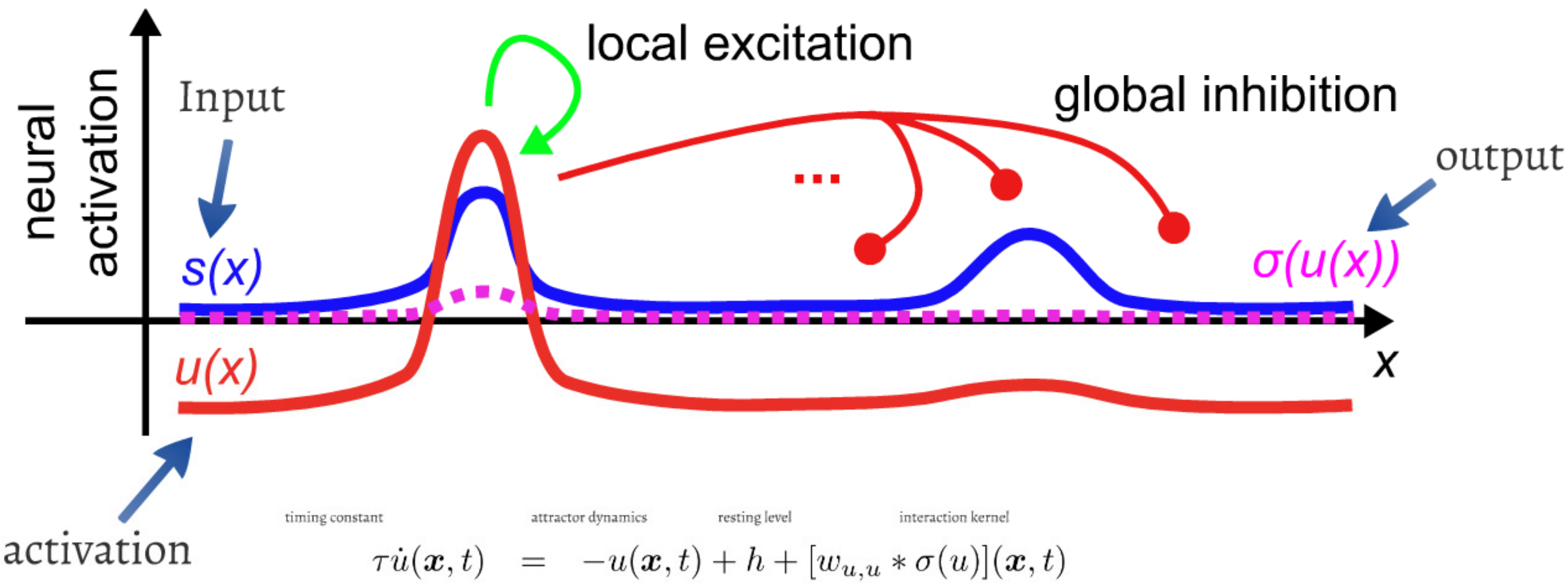
A Neural Process Account to Generate Goal Directed Arm Movements



Dynamic Field Theory



Dynamic Neural Field

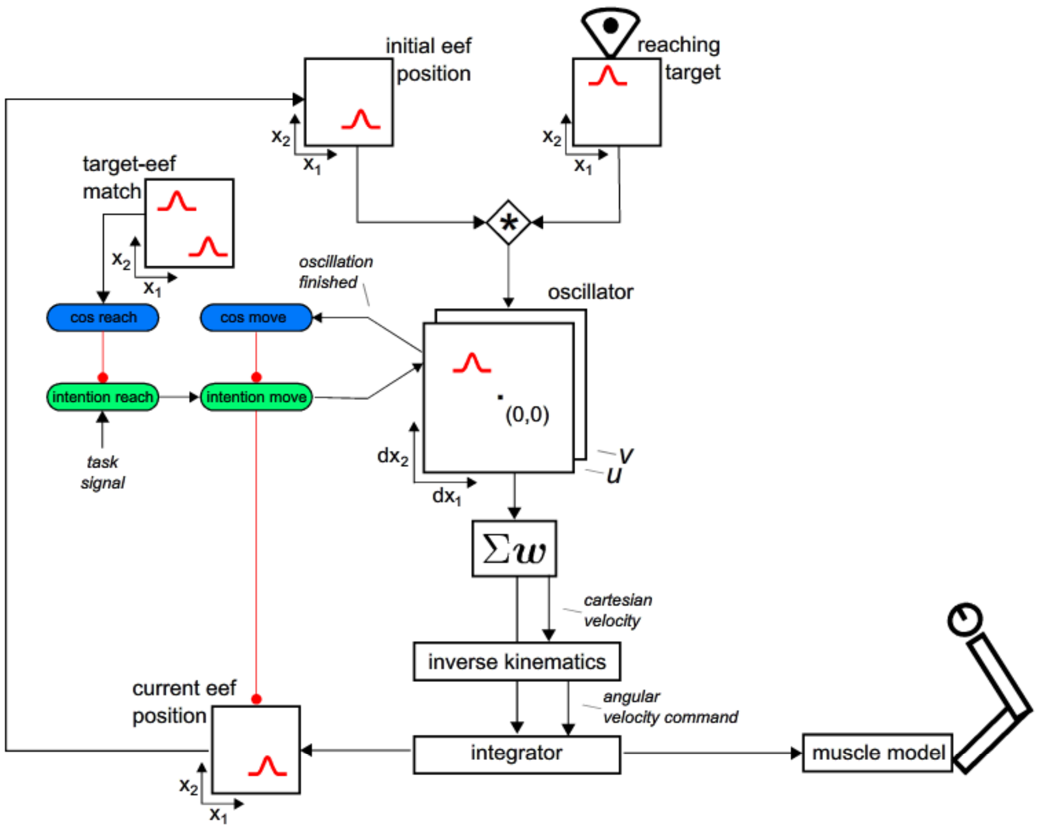


timing constant, attractor dynamics, resting level, interaction kernel

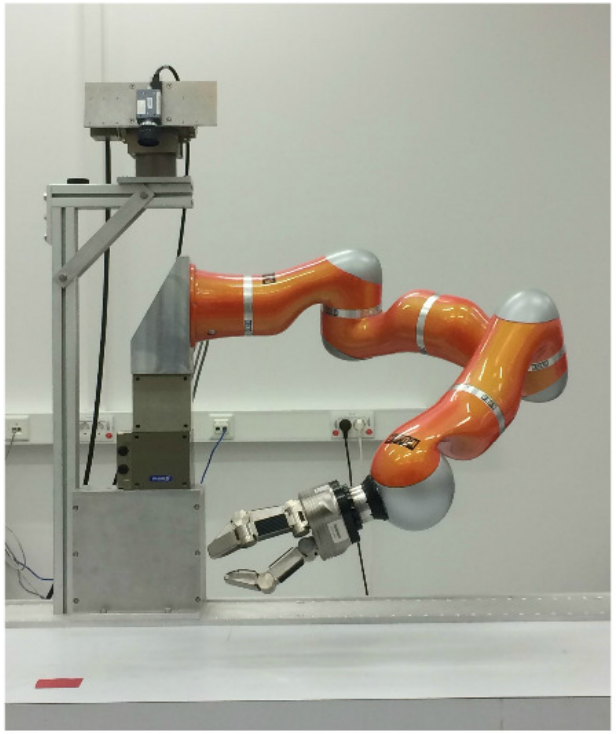
$$\tau \dot{u}(\boldsymbol{x}, t) = -u(\boldsymbol{x}, t) + h + [w_{u,u} * \sigma(u)](\boldsymbol{x}, t) + \sum_i s_i(\boldsymbol{x}, t)$$

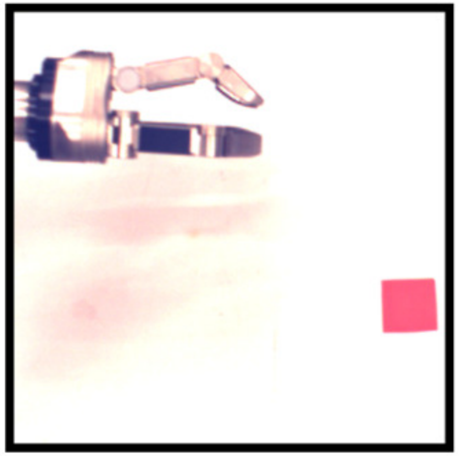
external inputs

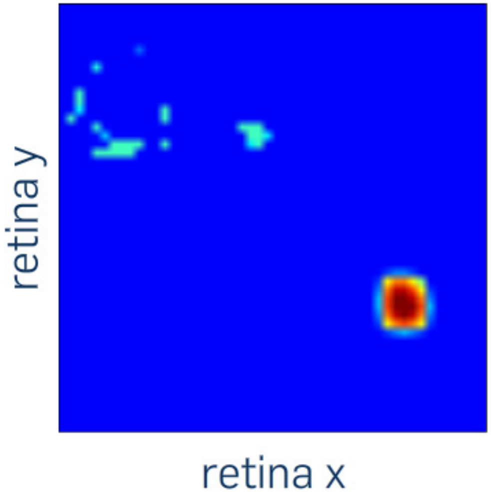
A Dynamic Field Architecture



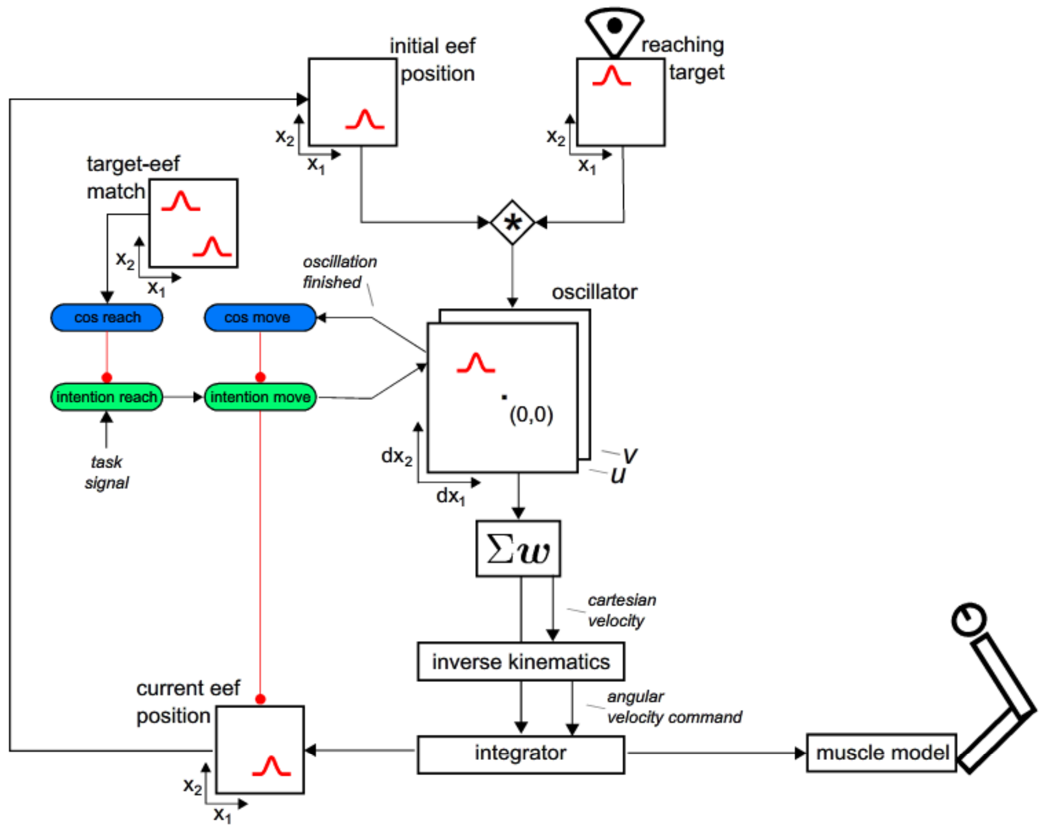
Target Representation



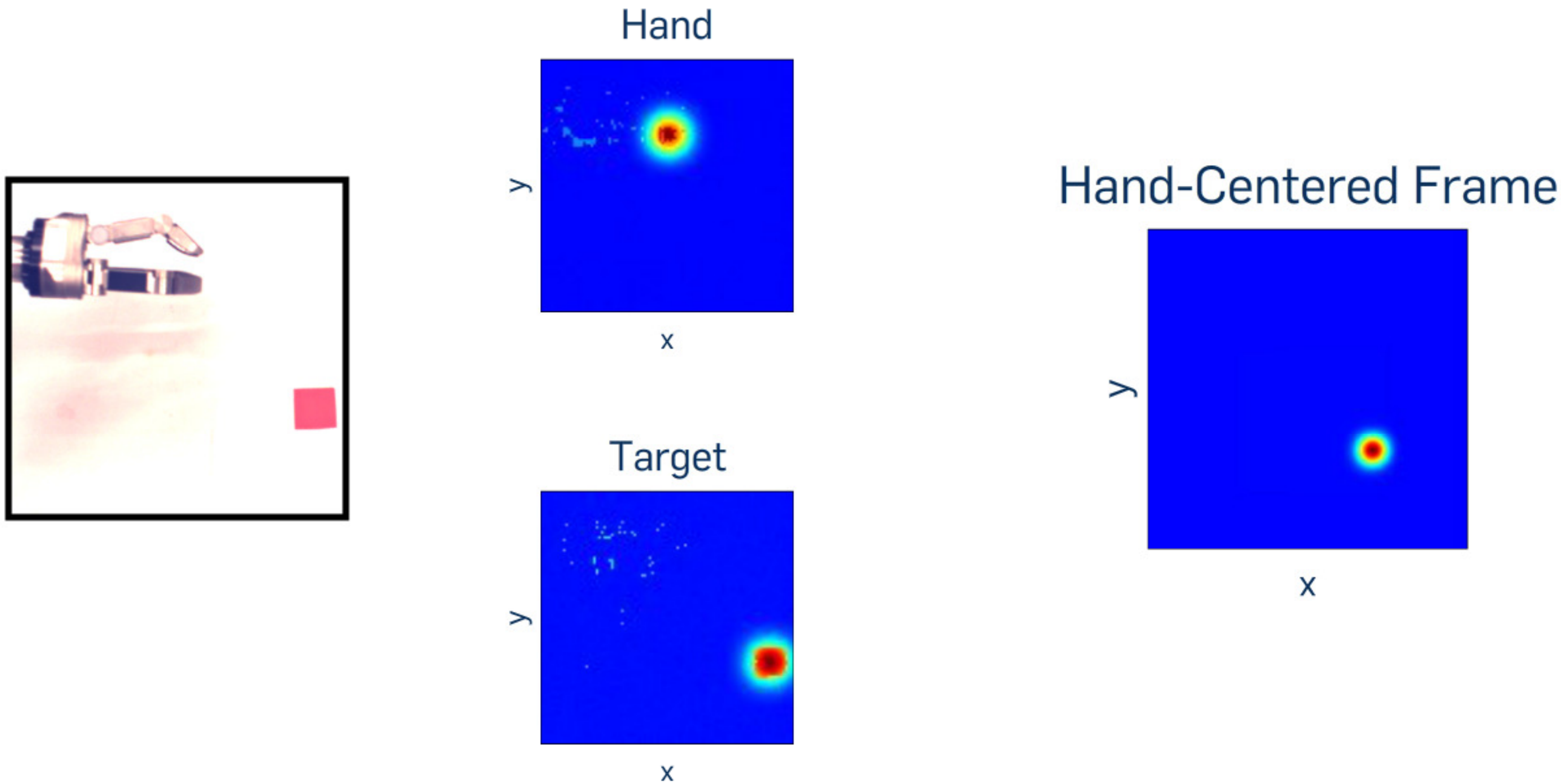




A Dynamic Field Architecture



Extracting a Movement Plan



Excursion: Convolution

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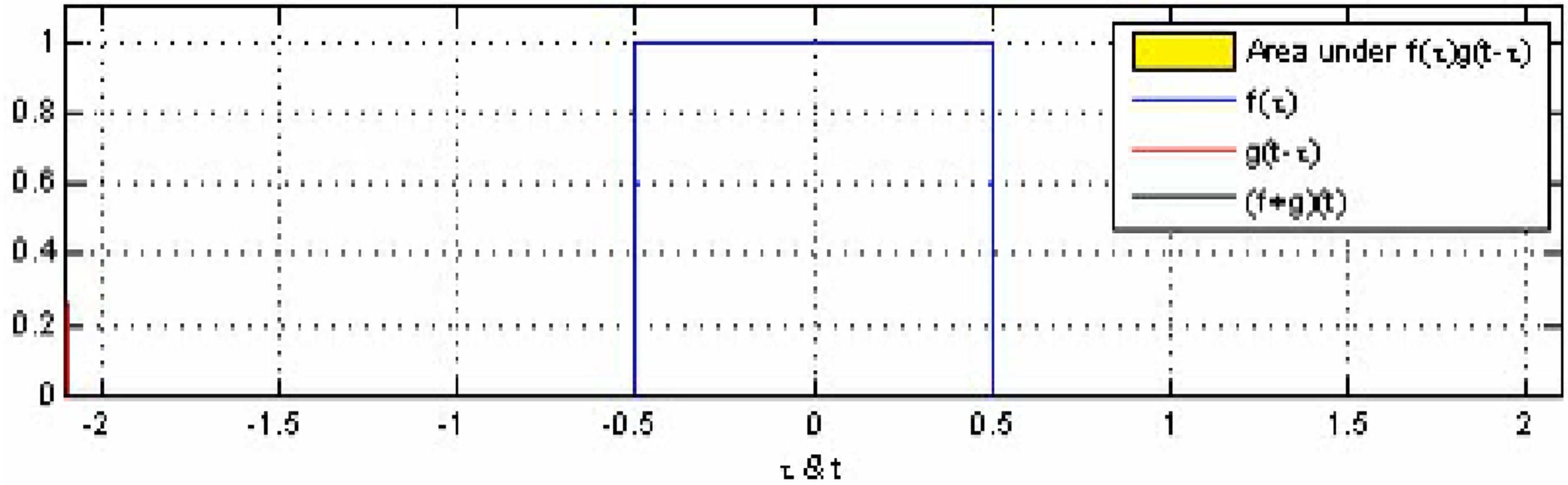
$$f(x) * g(x) = \int f(x')g(x - x')dx'$$



[en.wikipedia.org/wiki/Convolution]

Excursion: Convolution

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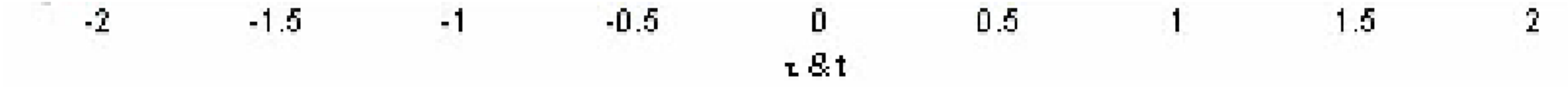

[en.wikipedia.org/wiki/Convolution]

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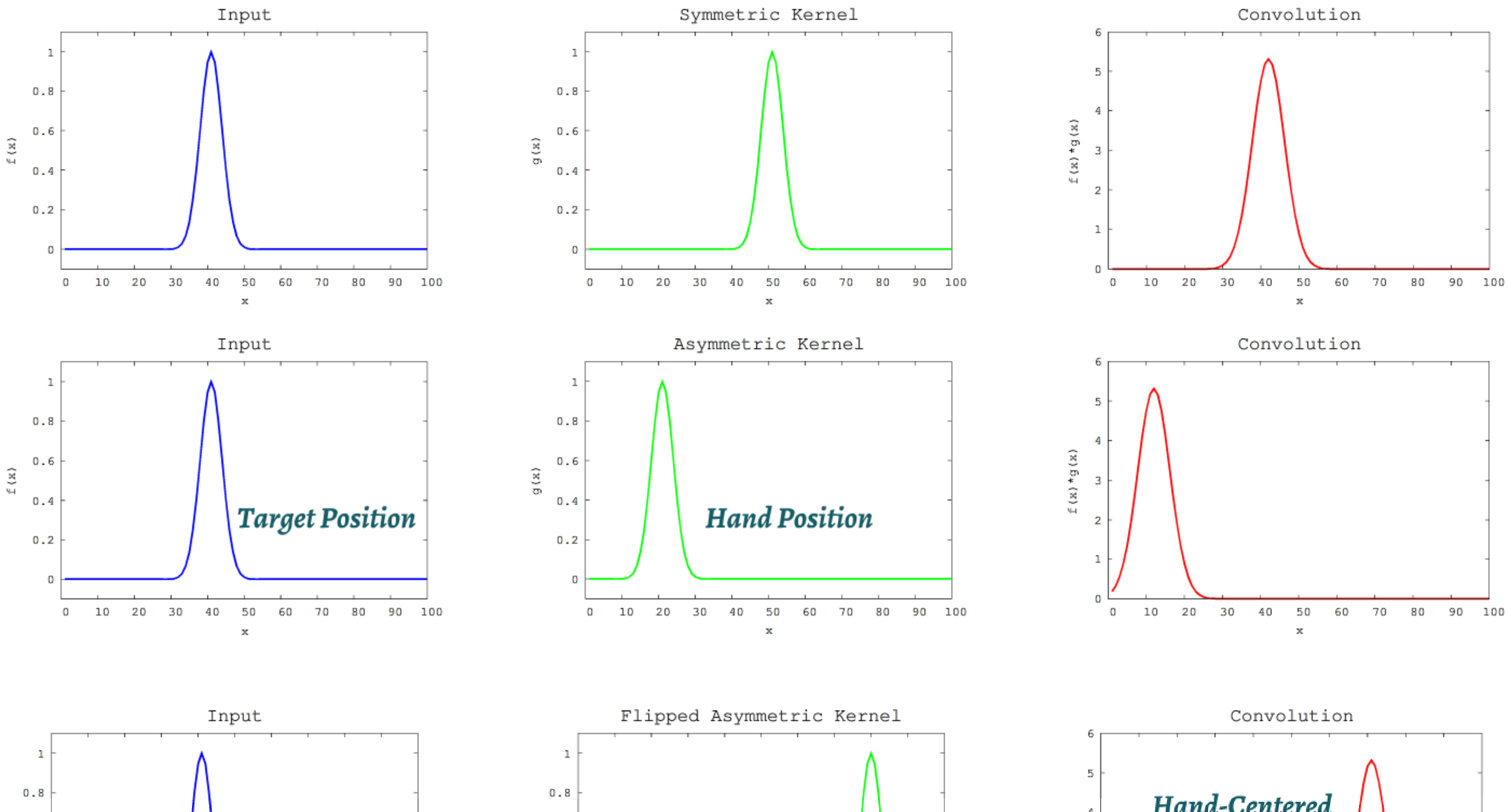
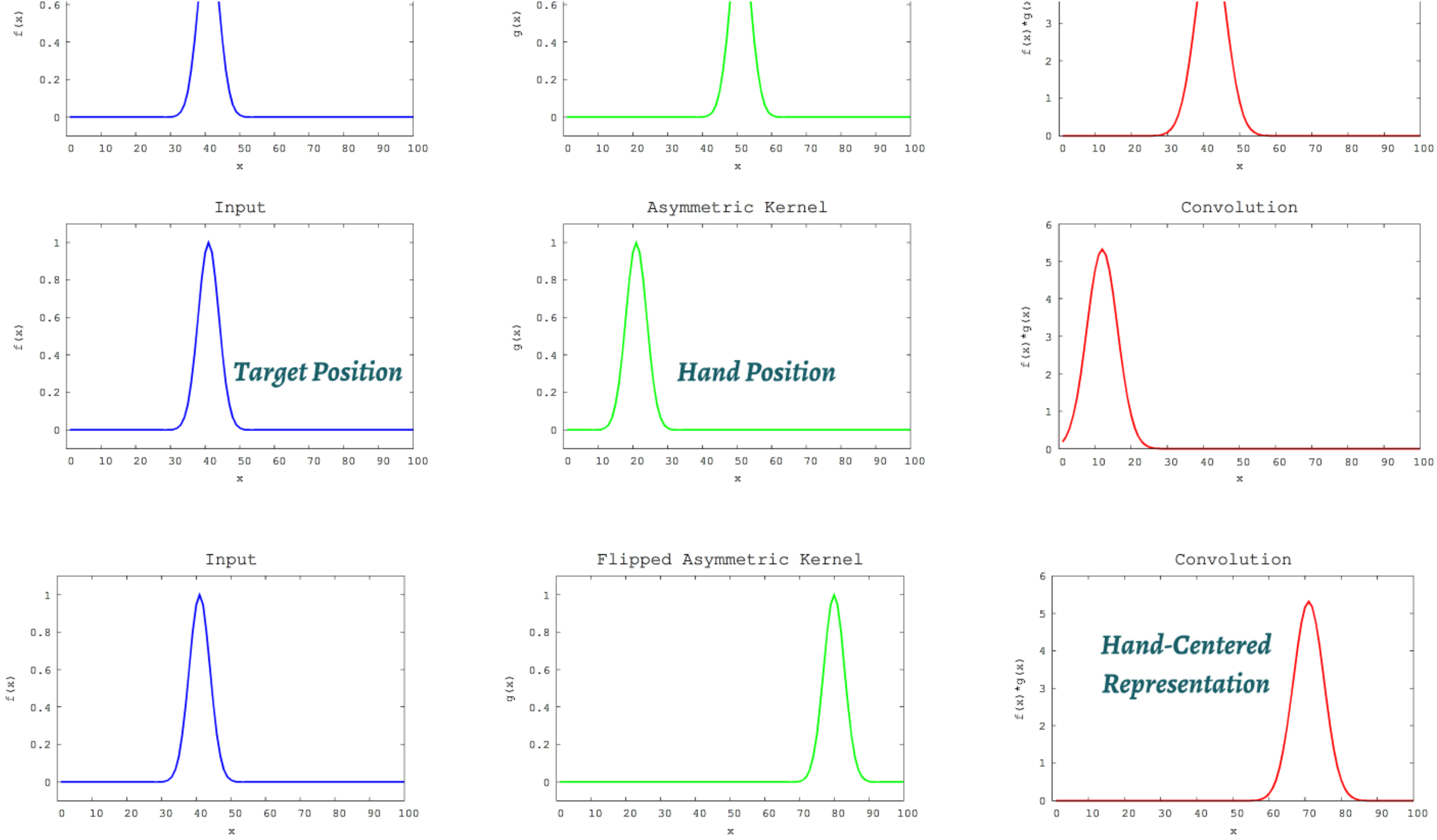
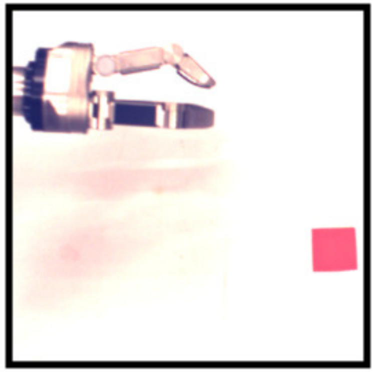
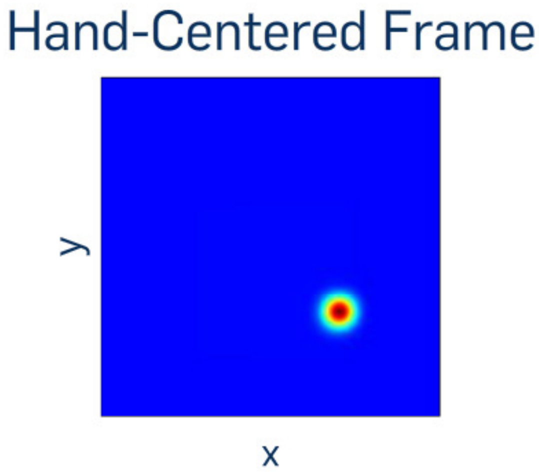




Input
Target Position
Asymmetric Kernel
Hand Position
Convolution
Input
Flipped Asymmetric Kernel
Convolution
Hand-Centered Representation

Extracting a Movement Plan

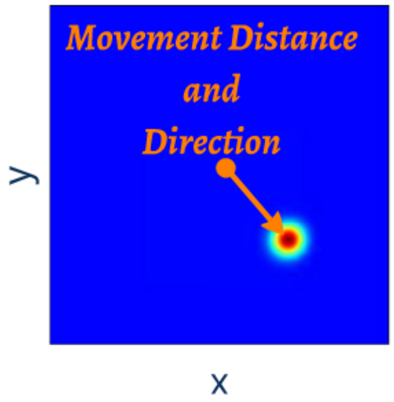




Excursion: Convolution

Extract Movement Parameters From Relative Frame

Hand-Centered Frame



Weight Matrix

$\mathbf{w}$

-3	-2	-1	0	1	2	3
-3	-2	-1	0	1	2	3
-3	-2	-1	0	1	2	3
-3	-2	-1	0	1	2	3
-3	-2	-1	0	1	2	3
-3	-2	-1	0	1	2	3
-3	-2	-1	0	1	2	3

x-direction

-3	-3	-3	-3	-3	-3	-3
-2	-2	-2	-2	-2	-2	-2
-1	-1	-1	-1	-1	-1	-1
0	0	0	0	0	0	0
1	1	1	1	1	1	1
2	2	2	2	2	2	2
3	3	3	3	3	3	3

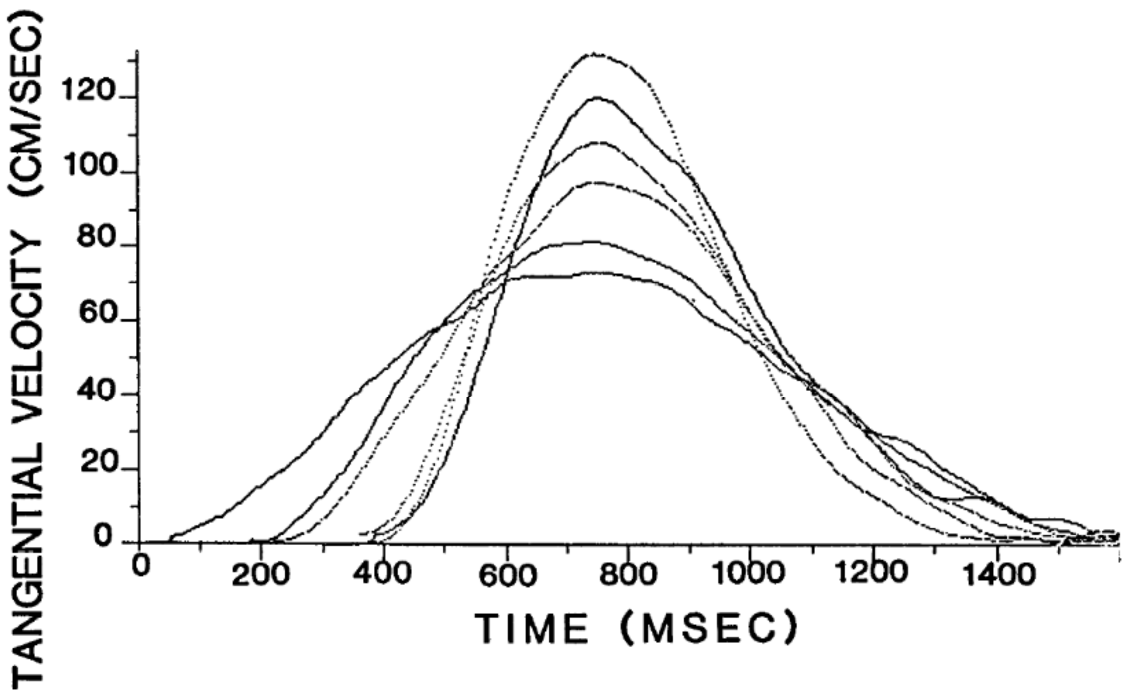
y-direction

Velocity

$\mathbf{v}$

$$\mathbf{v} = \iint \mathbf{w}(x, y)\sigma(u(x, y))\, dxdy$$

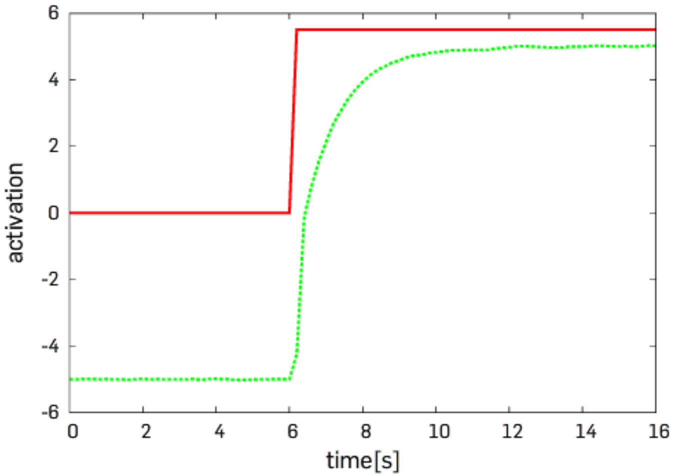
Velocity Profile of Human Arm Movements



[Atkeson,Hollerbach 1985]

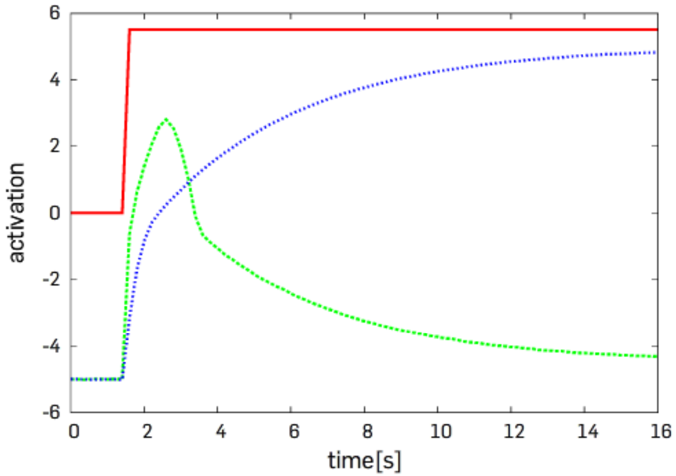
Generating a Bell Shaped Timing Profile

Single Node



$$\tau_u \dot{u}(t) = -u(t) + S(t) + h$$

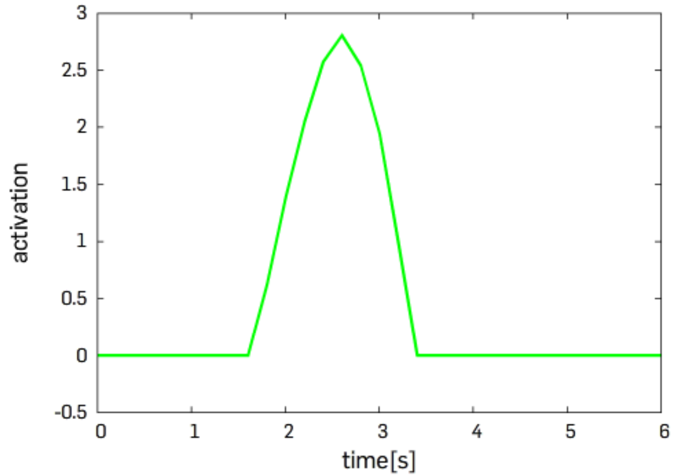
Two Nodes different Time-Scales



$$\tau_u \dot{u}(t) = -u(t) + S(t) + h - v(t)$$
$$\tau_v \dot{v}(t) = -v(t) + S(t) + h$$

$$\tau_u < \tau_v$$

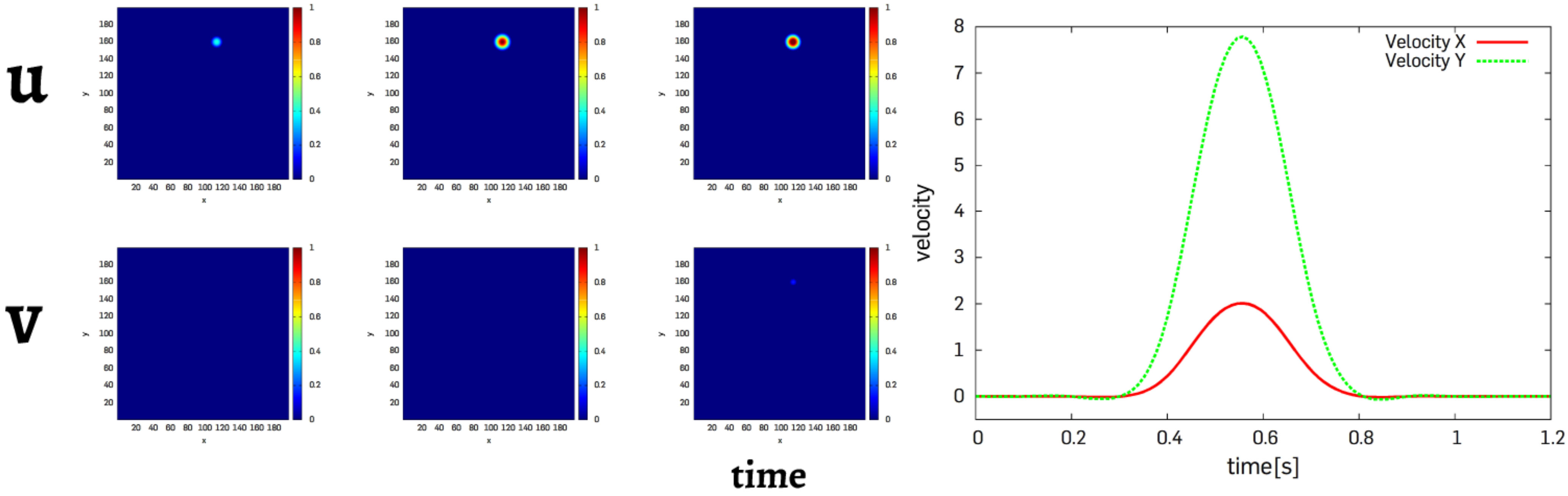
Sigmoided Activation



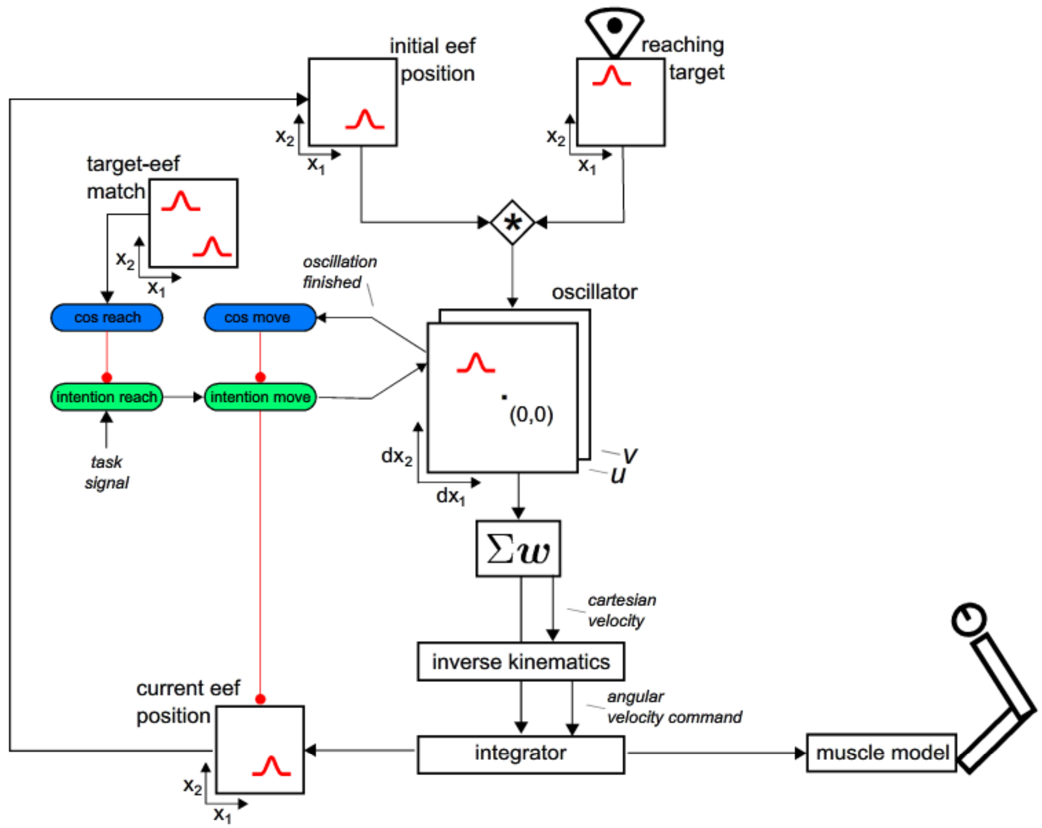
$$\Theta(u(t))$$

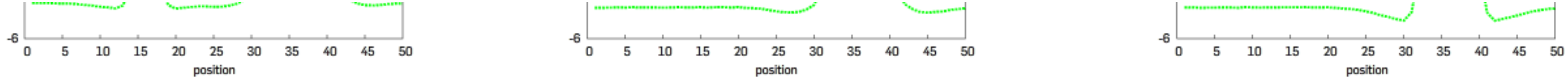
$$\Theta(x) = \begin{cases} x, & \text{if } x > 0 \\ 0, & \text{otherwise} \end{cases}$$

Combine this Oscillator with the Relative 2D-Field



A Dynamic Field Architecture

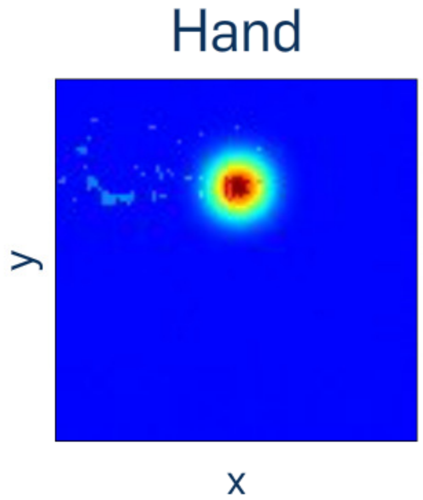




Updating the Arm Position: Rate to Space Code

$$\dot{\boldsymbol{p}} = \boldsymbol{v}$$

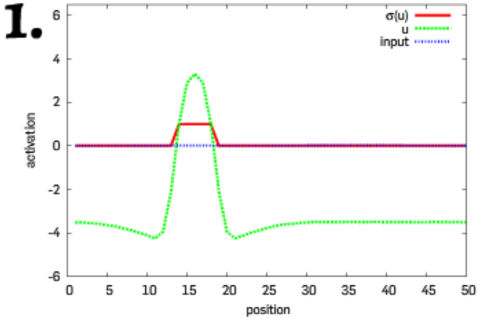
$$\boldsymbol{p} = \begin{pmatrix} p_x \\ p_y \end{pmatrix}$$



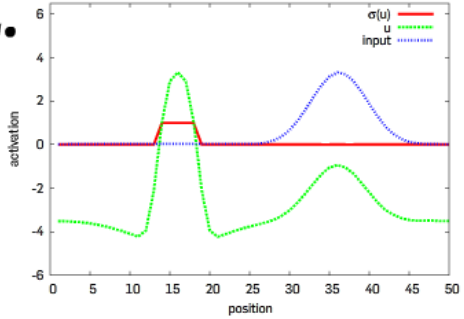
$$s_p(x, y, t) = c \ \exp\left(-\left(\frac{(x - p_x)^2}{2\sigma_x^2} + \frac{(y - p_y)^2}{2\sigma_y^2}\right)\right)$$

Updating the Arm Position:
Selective Memory Field

1.



2.



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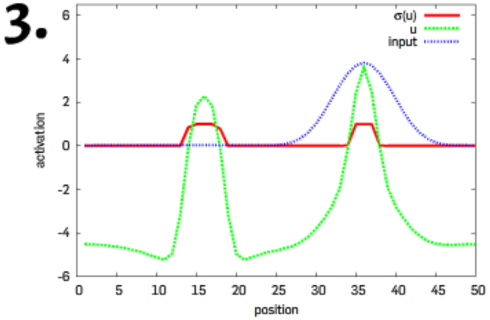

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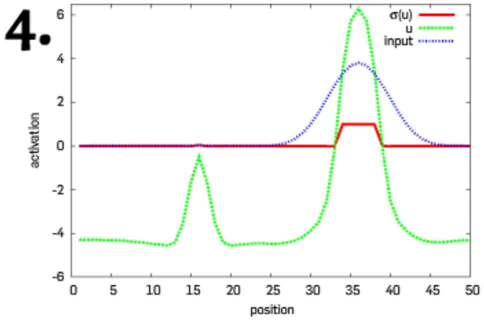
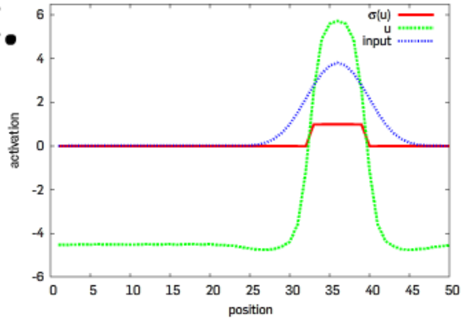
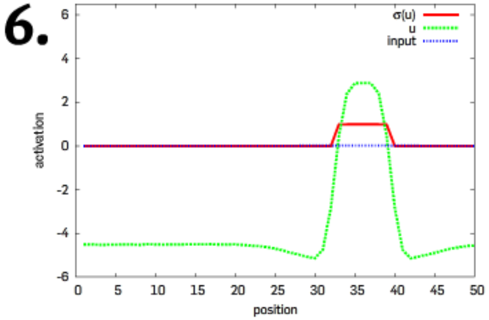


5.



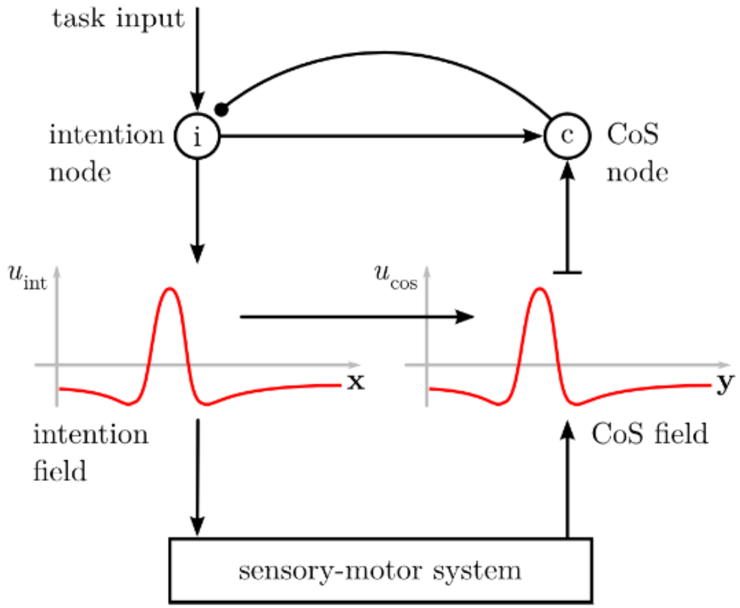
6.

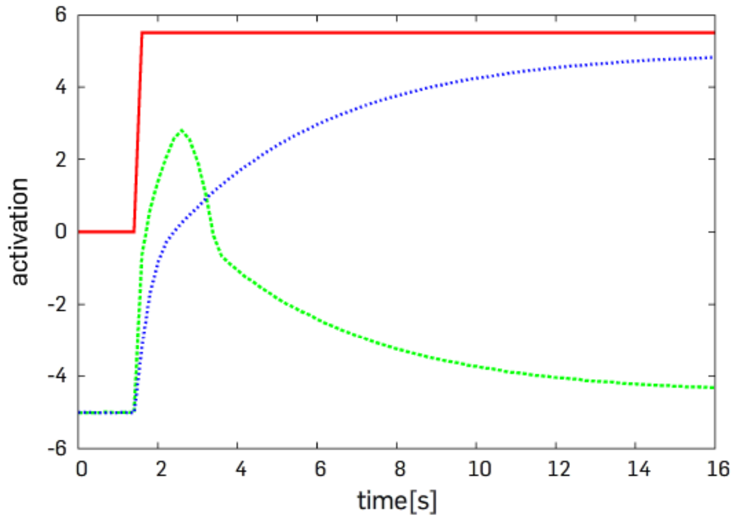


Updating the Arm Position:

Organizing a Single Movement

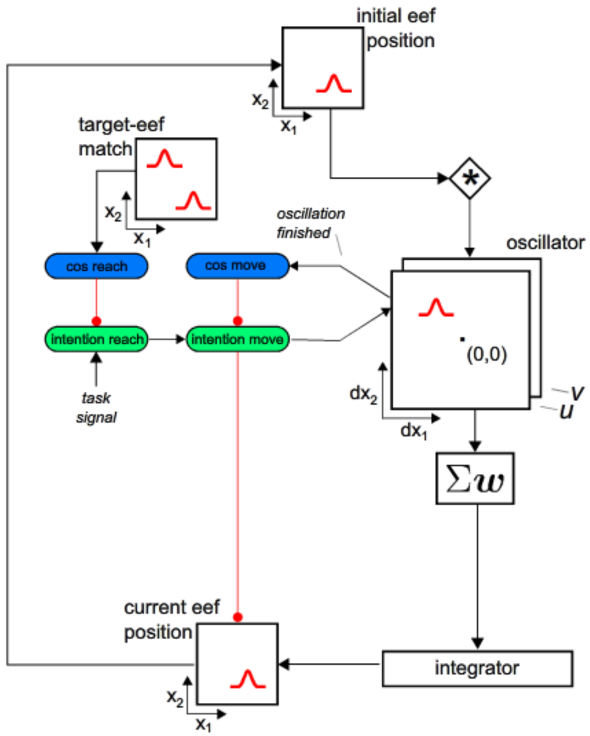
Elementary
BEHAVIOR

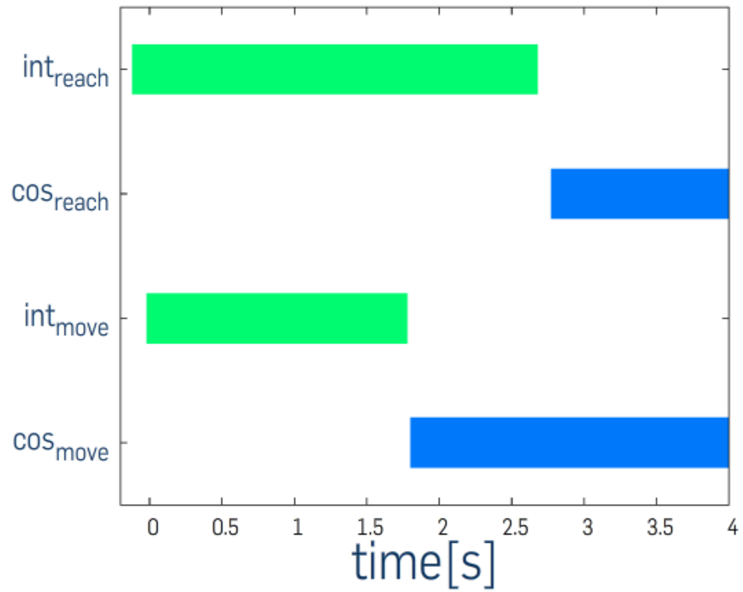




$$\tau_u \dot{u}(t) = -u(t) + S(t) + h - v(t)$$
$$\tau_v \dot{v}(t) = -v(t) + S(t) + h$$

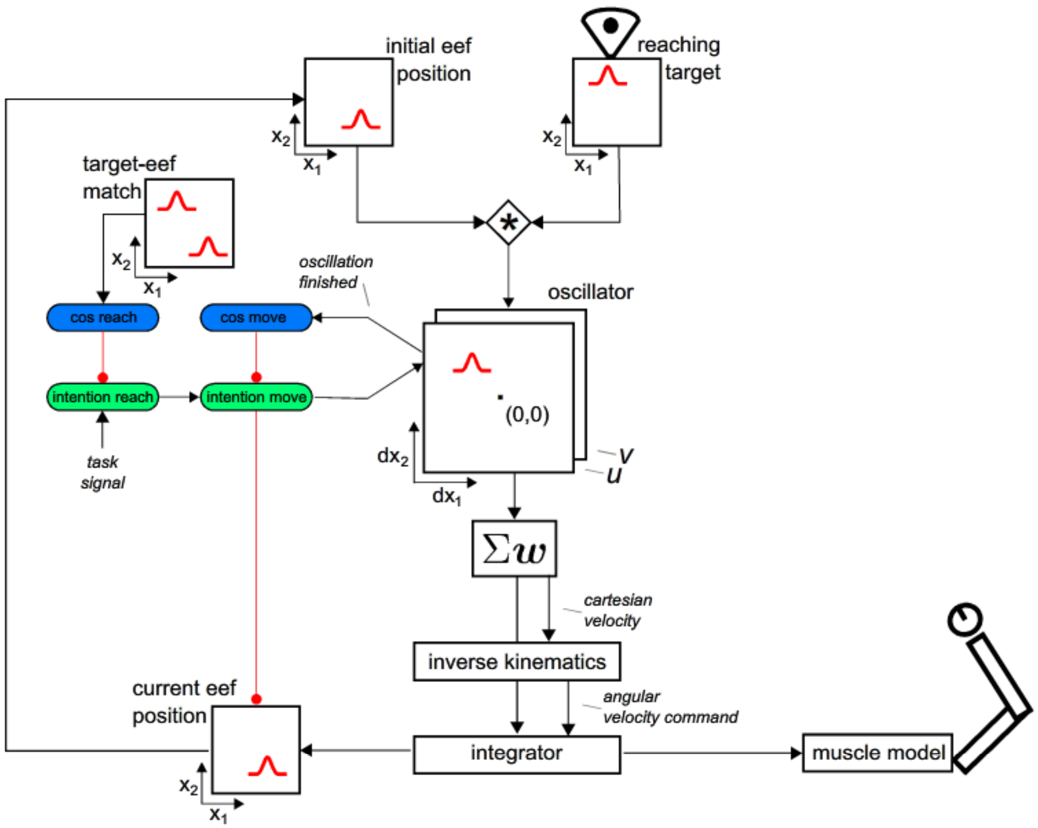
Organizing a Single Movement



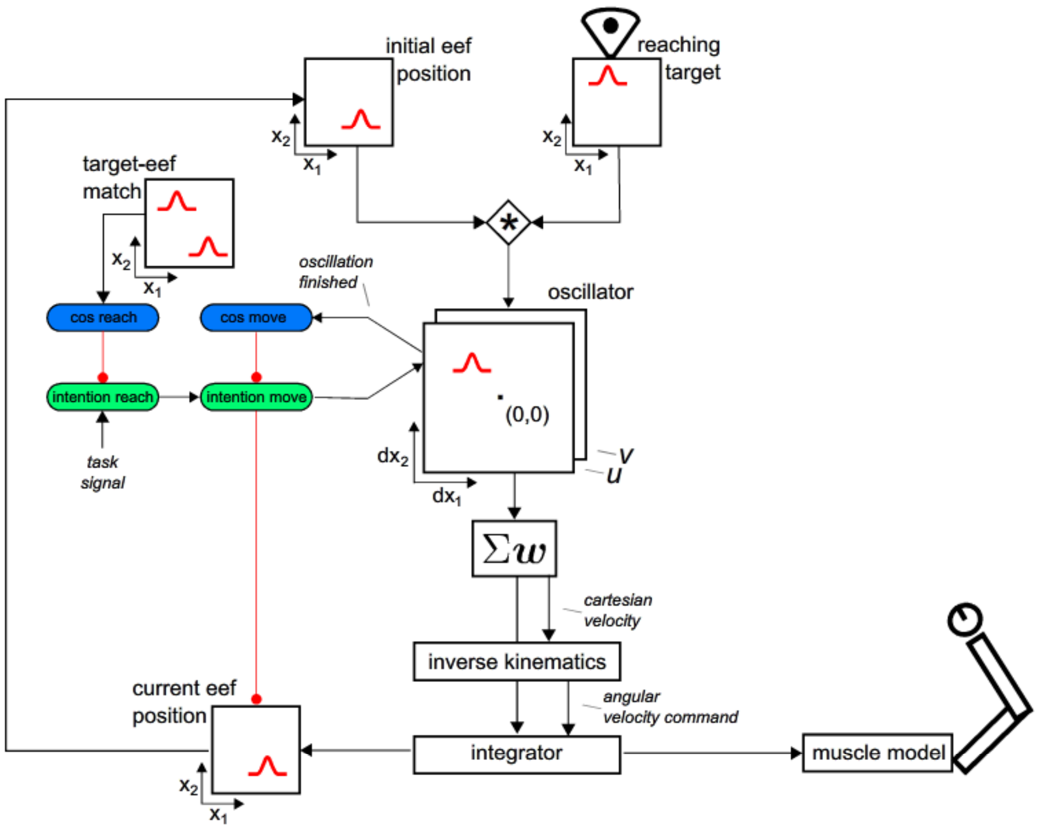


Organizing a Single Movement

A Dynamic Field Architecture

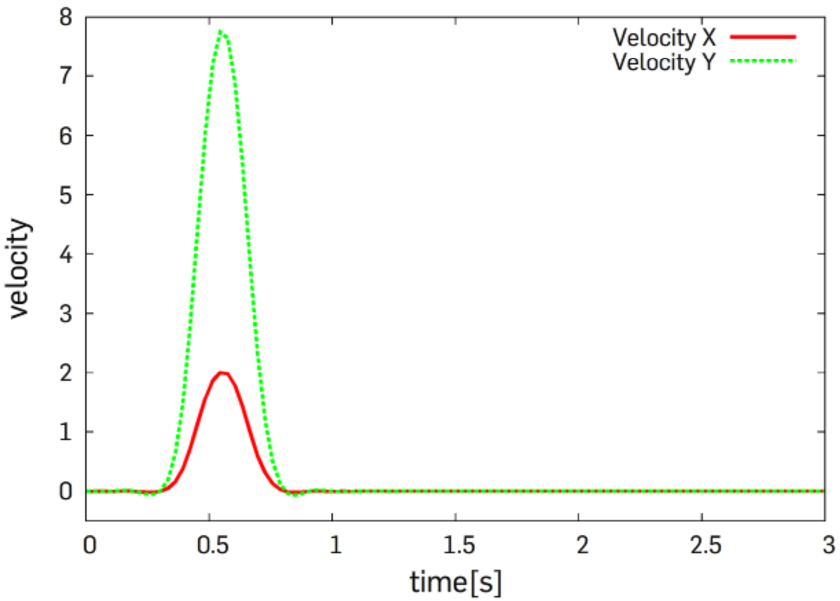


A Dynamic Field Architecture



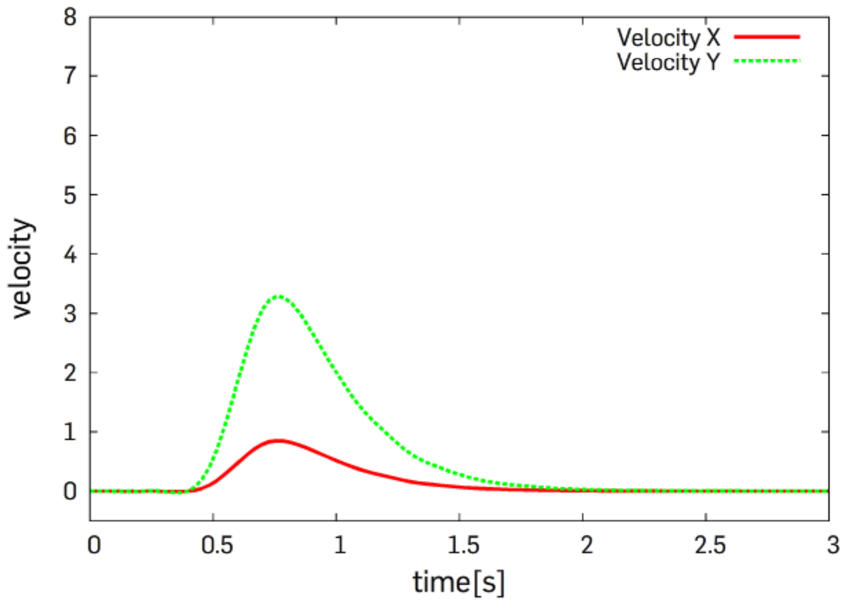
Muscle Model

Velocity Signal



v

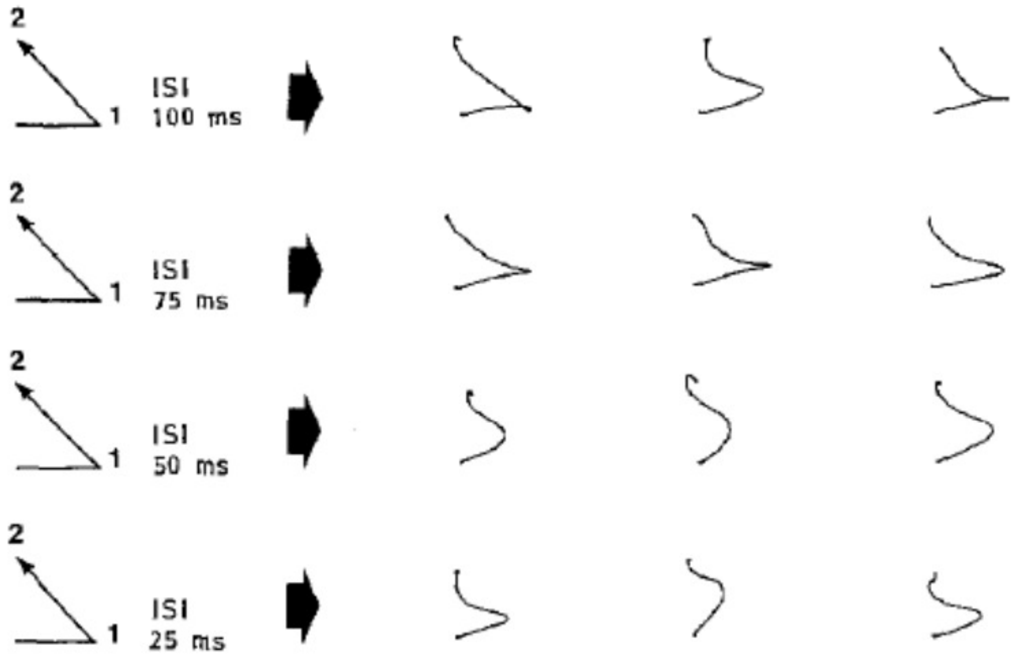
Delayed Velocity Signal



$$\ddot{\phi} = -K(\phi - \theta) - B\dot{\phi}$$

harmonic oscillator

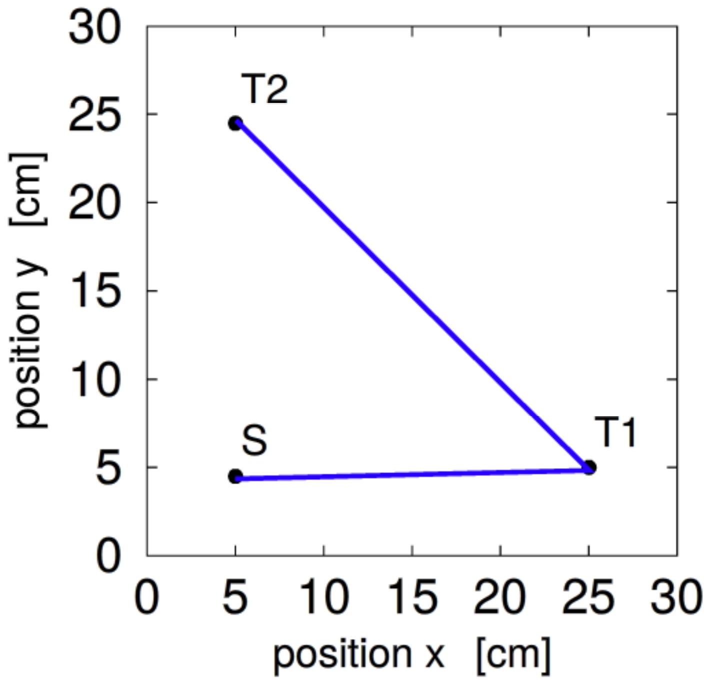
Online Updating of Human Arm Movements



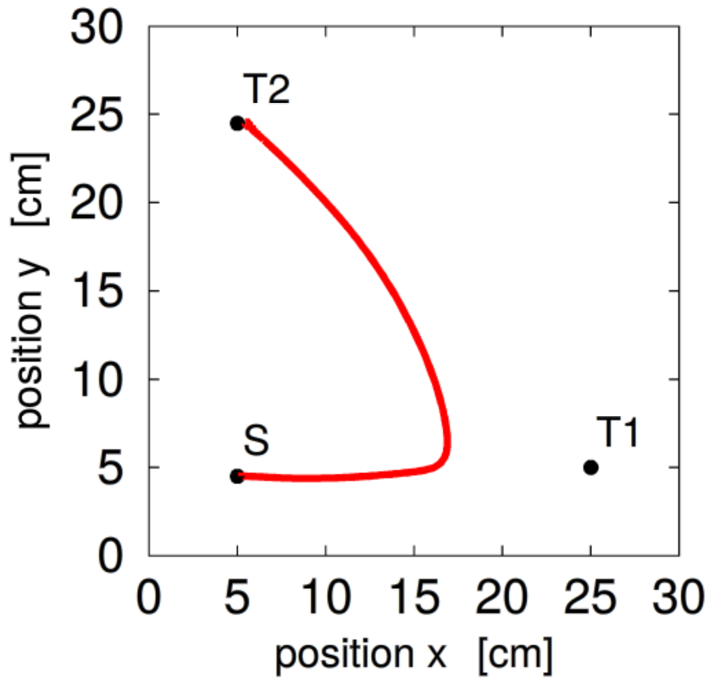
[van Sonderen, van der Gon, Gielen 1988]

[van Sonderen, van der Gon, Gielen 1988]

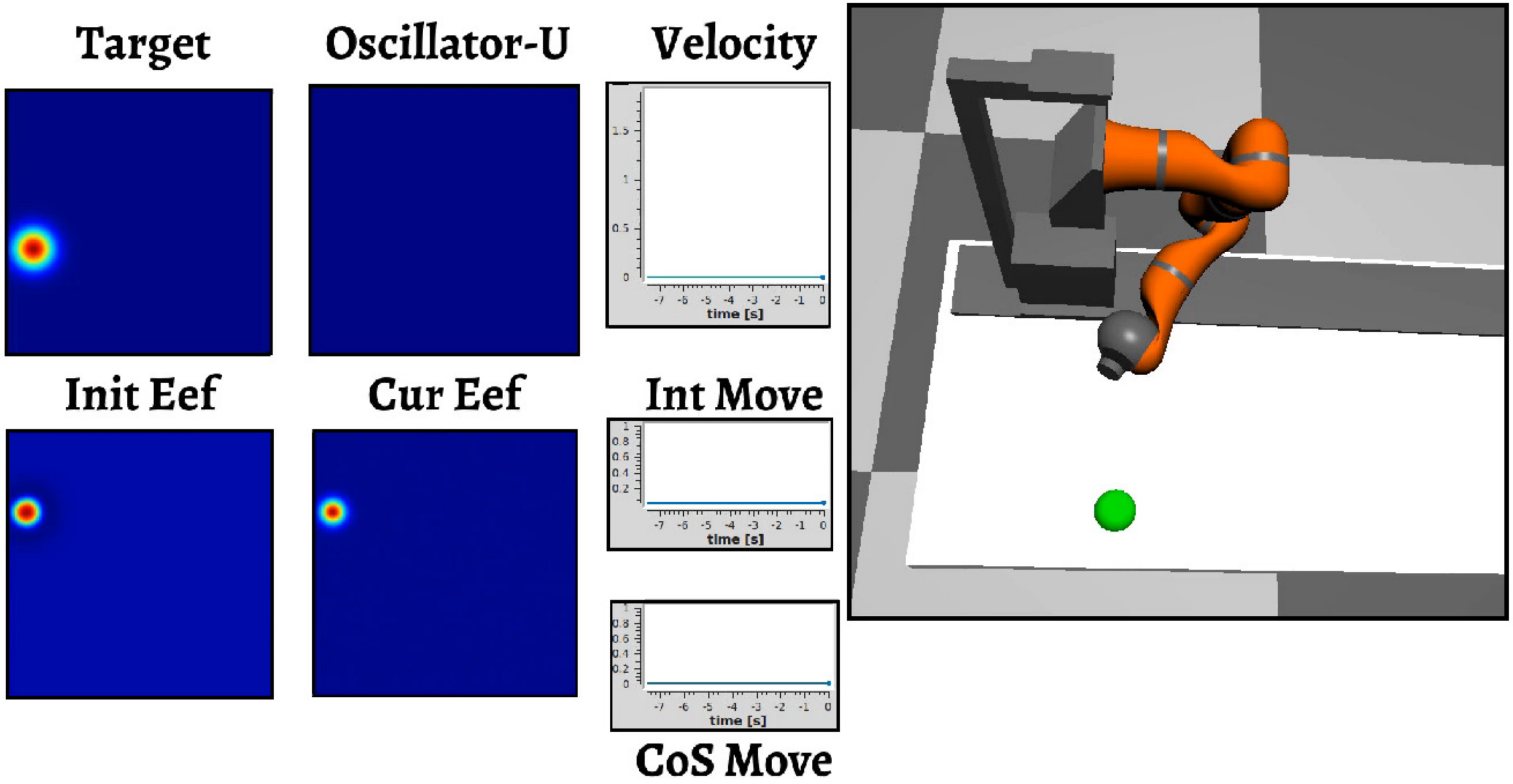
Delay enables smooth updating



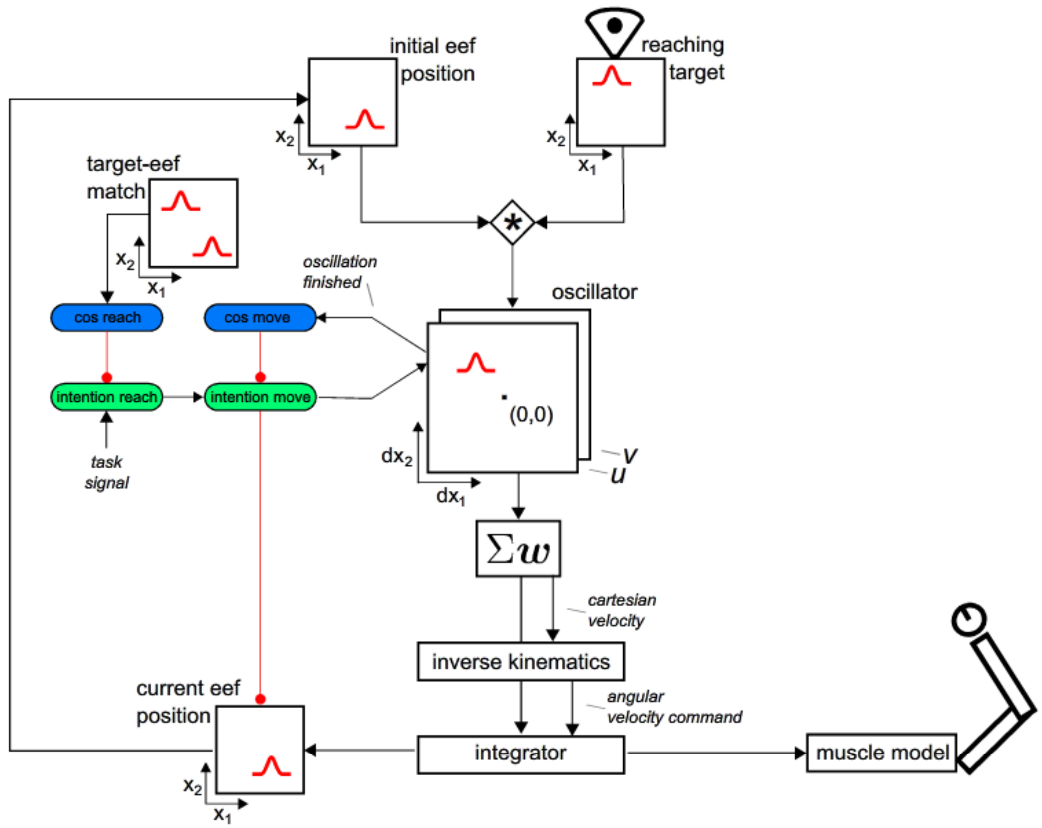
planned movement



delayed movement


Target
Oscillator-U
Velocity
time [s]
Init Eef
Cur Eef
Int Move
time [s]
time [s]
CoS Move

A Dynamic Field Architecture



Conclusion

- Pathway from Perception to Motor
- Neural Oscillator generates Timing
- Elementary Behaviors enable Autonomy