Compliance in Perceptual Control Systems: Insights and Implications

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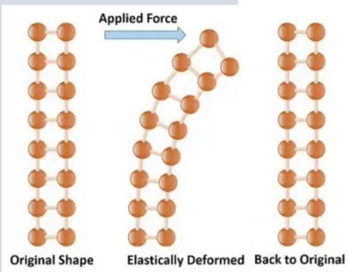
What is 'Compliance'?



https://www.tribonet.org/wiki/elastic-deformation/

- The property of a material of undergoing elastic deformation when subjected to an applied force (the reciprocal of stiffness)

Returns to original state

- The act of conforming, acquiescing, or yielding

Adopts new state

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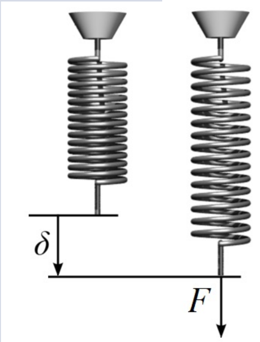
Compliant Systems



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https://commons.wikimedia.org/w/index.php?curid=80080175

JLS Automation and Soft Robotics grippers
https://www.snackandbakery.com/articles/89167-jls-automation-and-soft-robotics-grippers

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Active/Passive Compliance in Robotics

https://www.thinkrobotics.co.nz/kuka-robots.html

Compliance needs to be programmed explicitly due to high impedance 'backdrivability'

Compliance is implicit in elastic construction material

Diamond, A., Knight, R., Devereux, D. & Holland, O. (2012) "Anthropomimetic Robots: Concept, Construction and Modelling", *International Journal of Advanced Robotic Systems*, vol. 9, pp. 1-14.

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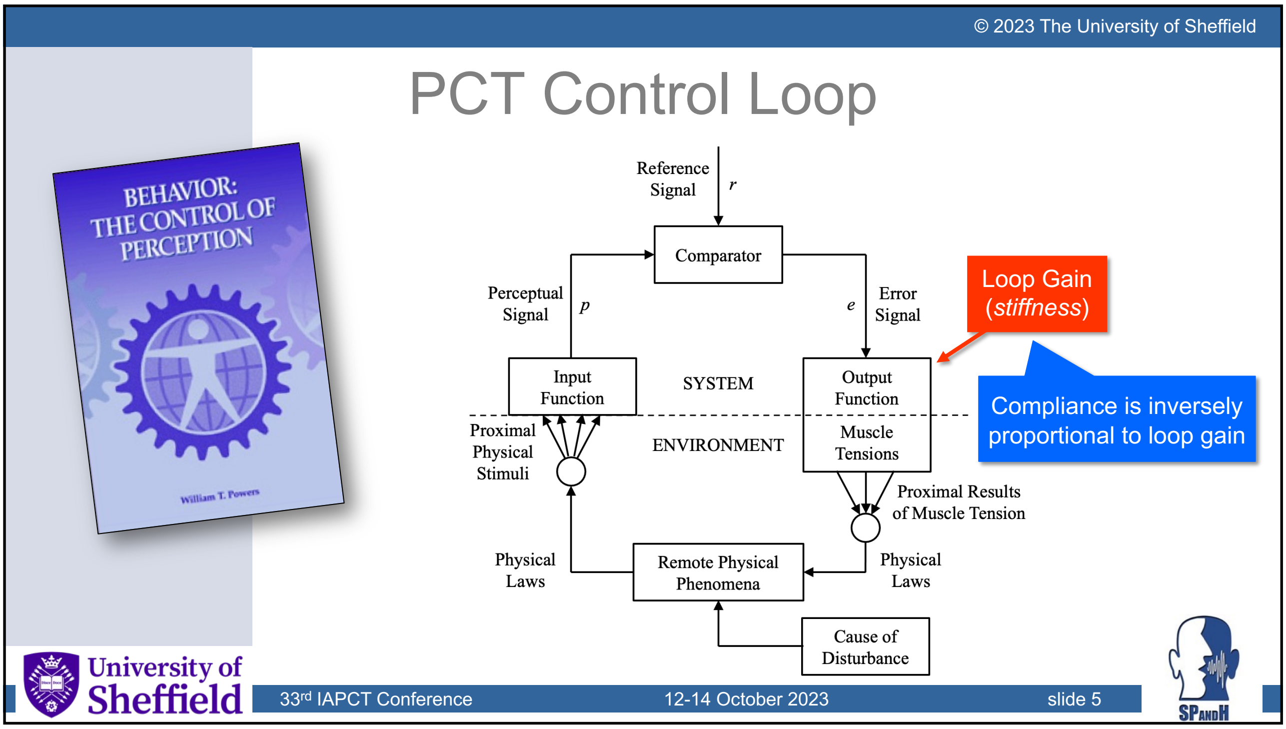

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PCT Control Loop
BEHAVIOR: THE CONTROL OF PERCEPTION
William T. Powers
Reference Signal
r
Comparator
Perceptual Signal
p
e
Error Signal
Loop Gain (stiffness)
Input Function
SYSTEM
Output Function
Compliance is inversely proportional to loop gain
Proximal Physical Stimuli
ENVIRONMENT
Muscle Tensions
Proximal Results of Muscle Tension
Physical Laws
Remote Physical Phenomena
Physical Laws
Cause of Disturbance
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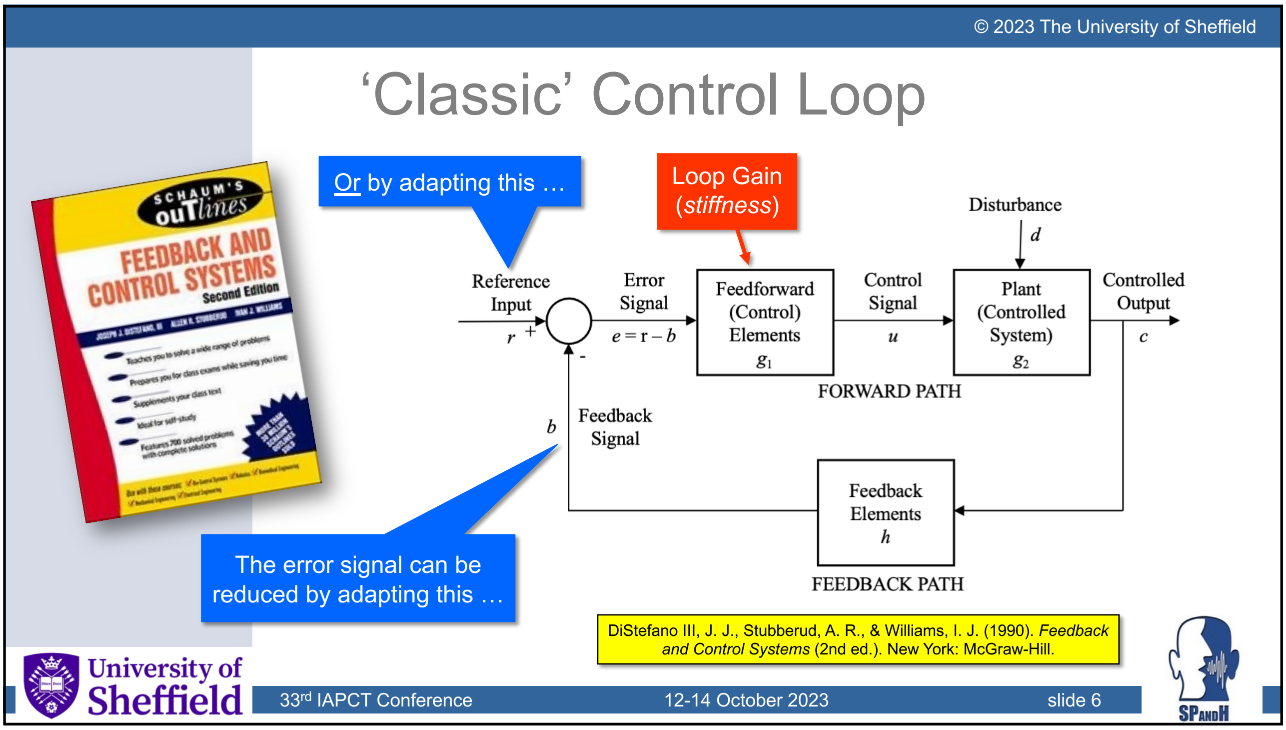

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'Classic' Control Loop
SCHAUM'S outlines
FEEDBACK AND CONTROL SYSTEMS
Second Edition
Or by adapting this …
Loop Gain (stiffness)
Disturbance
d
Reference Input
r
+
-
Error Signal
e = r – b
Feedforward (Control) Elements
g1
Control Signal
u
Plant (Controlled System)
g2
Controlled Output
c
FORWARD PATH
b
Feedback Signal
Feedback Elements
h
FEEDBACK PATH
The error signal can be reduced by adapting this …
DiStefano III, J. J., Stubberud, A. R., & Williams, I. J. (1990). Feedback and Control Systems (2nd ed.). New York: McGraw-Hill.
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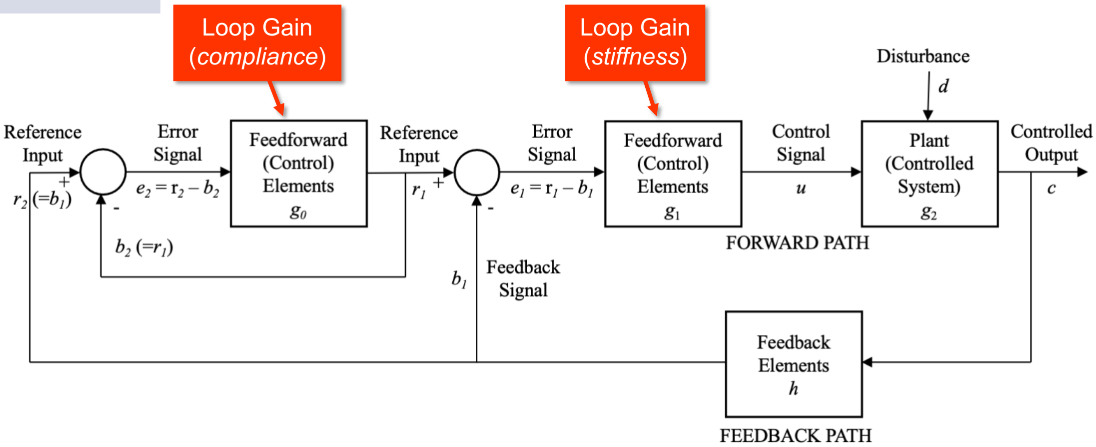
‘Compliant’ Control Loop



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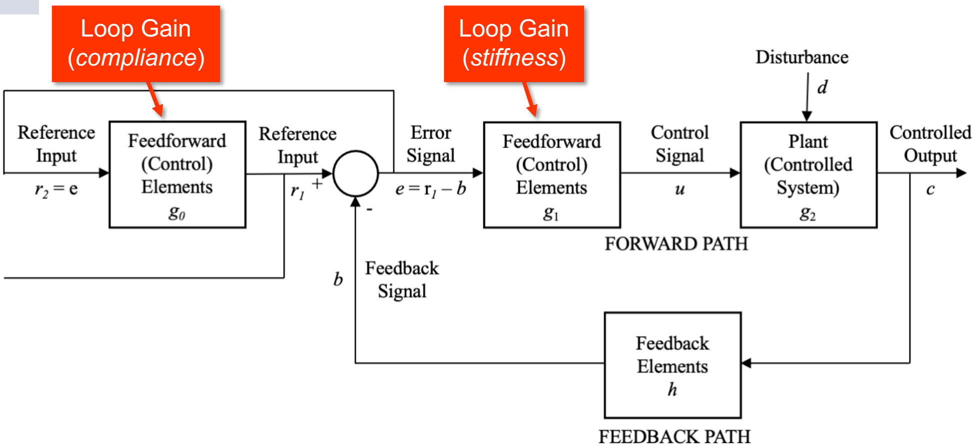
‘Compliant’ Control Loop



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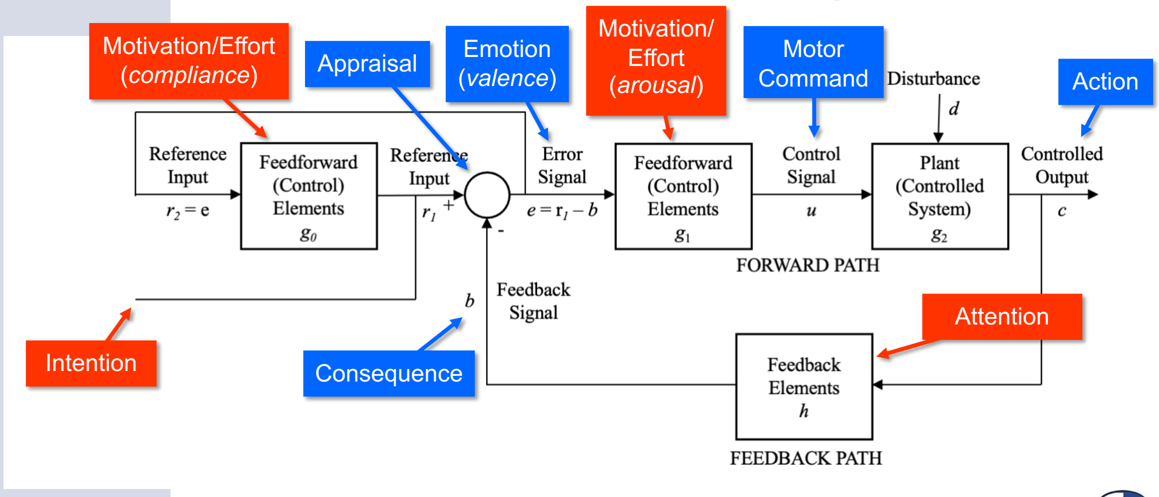
‘Affective’ Control Loop



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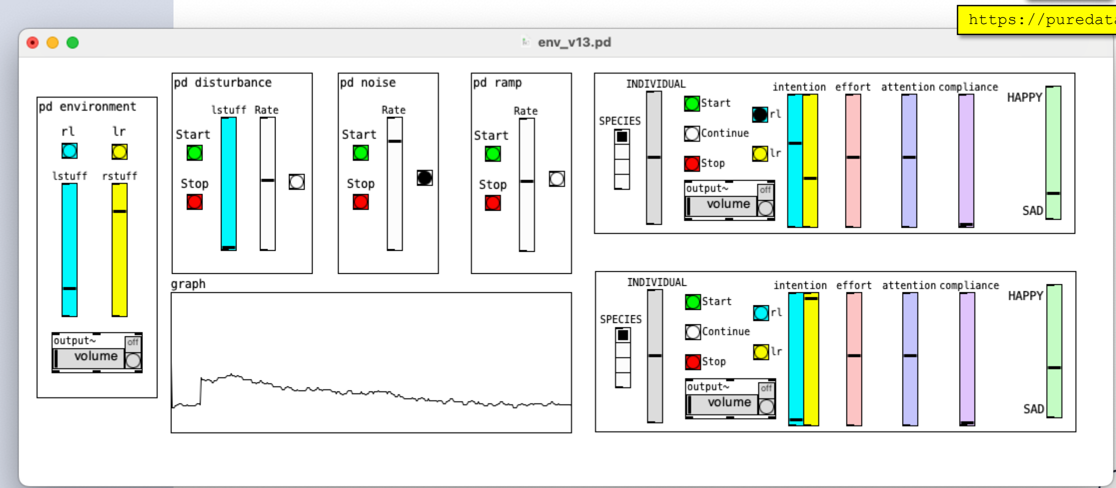
Simulation Environment

Pd
https://puredata.info



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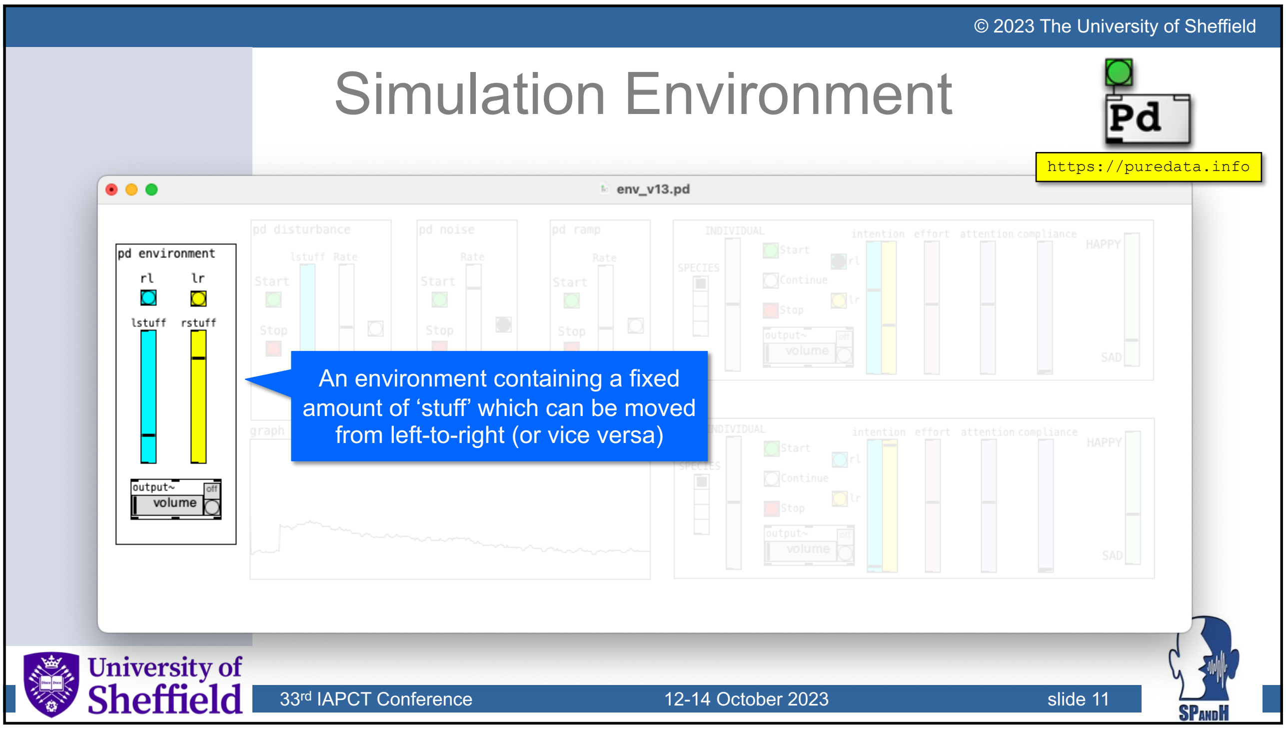
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Simulation Environment
Pd
https://puredata.info
env_v13.pd
pd environment
rl
lr
lstuff
rstuff
output~
volume
An environment containing a fixed amount of 'stuff' which can be moved from left-to-right (or vice versa)
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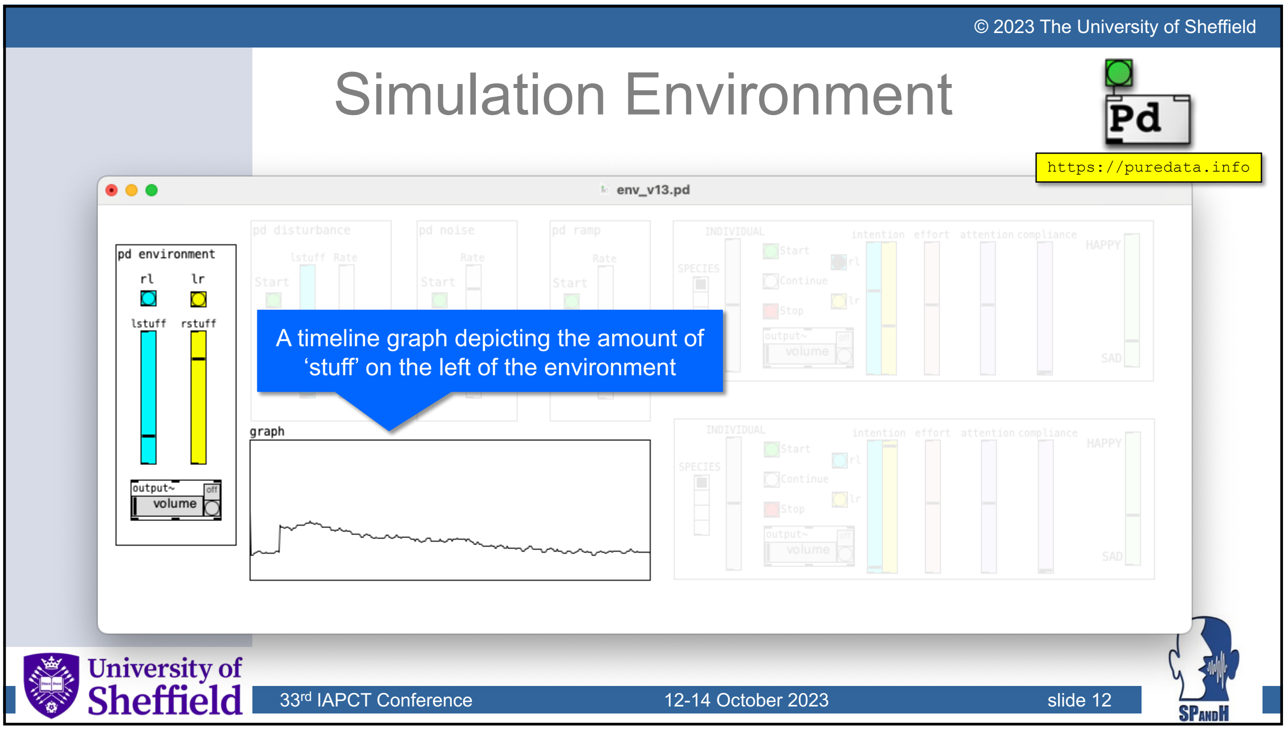
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Simulation Environment
Pd
https://puredata.info
env_v13.pd
pd environment
rl
lr
lstuff
rstuff
output~
volume
A timeline graph depicting the amount of 'stuff' on the left of the environment
graph
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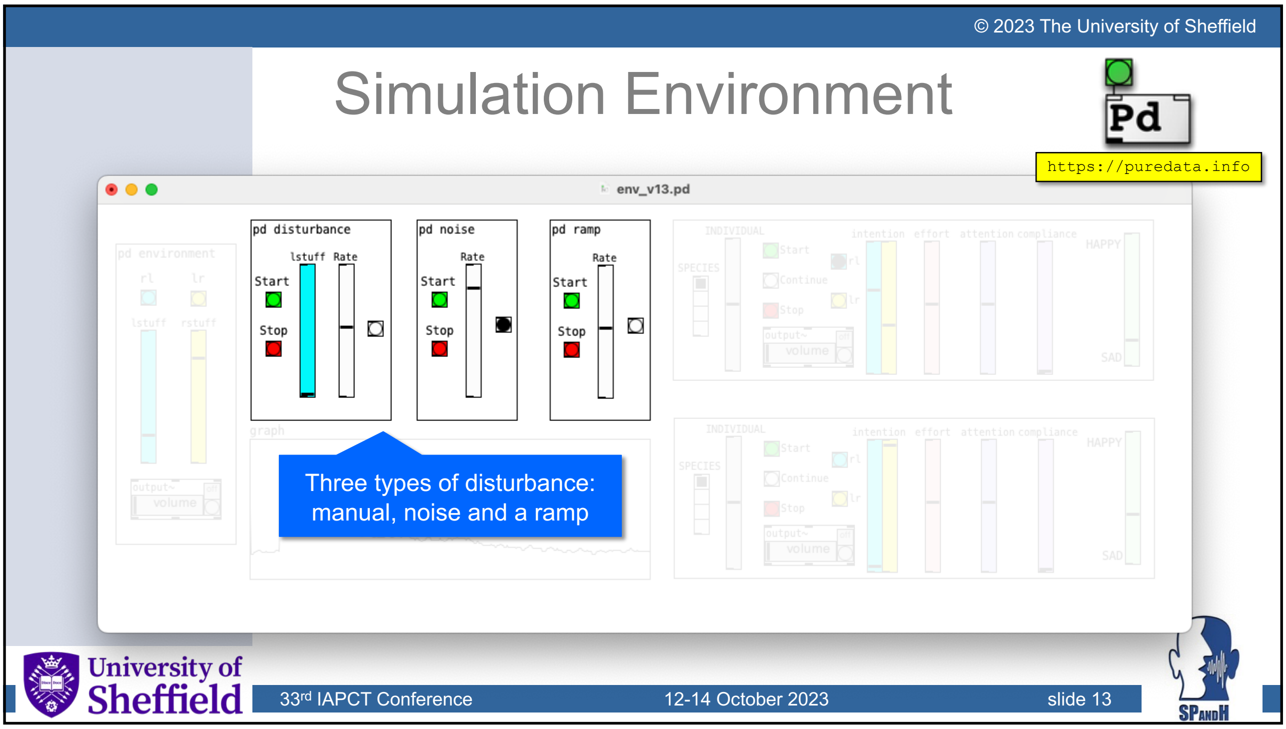
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Simulation Environment
Pd
https://puredata.info
env_v13.pd
pd disturbance
lstuff Rate
Start
Stop
pd noise
Rate
Start
Stop
pd ramp
Rate
Start
Stop
Three types of disturbance:
manual, noise and a ramp
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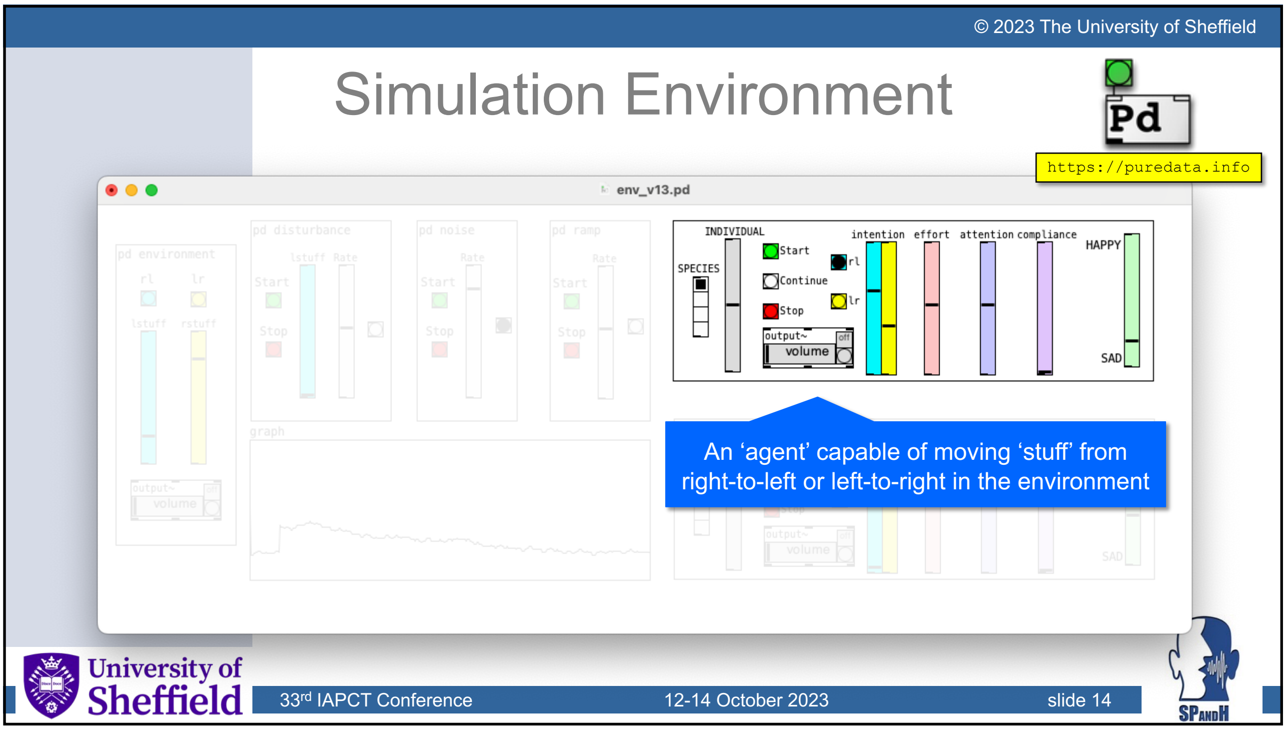
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Simulation Environment
Pd
https://puredata.info
env_v13.pd
INDIVIDUAL
SPECIES
Start
Continue
Stop
rl
lr
output~
volume
intention effort attention compliance
HAPPY
SAD
An 'agent' capable of moving 'stuff' from
right-to-left or left-to-right in the environment
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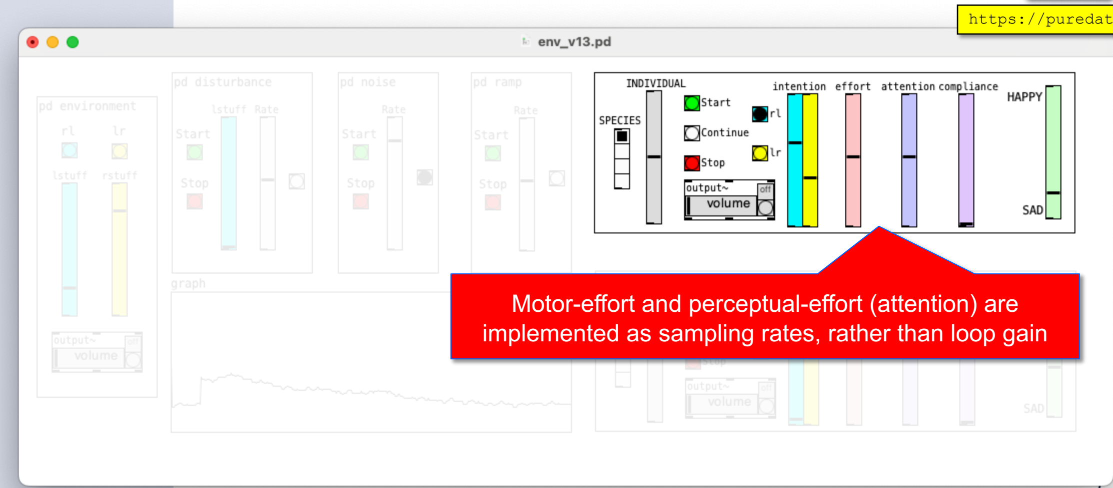
Simulation Environment

https://puredata.info



Motor-effort and perceptual-effort (attention) are implemented as sampling rates, rather than loop gain

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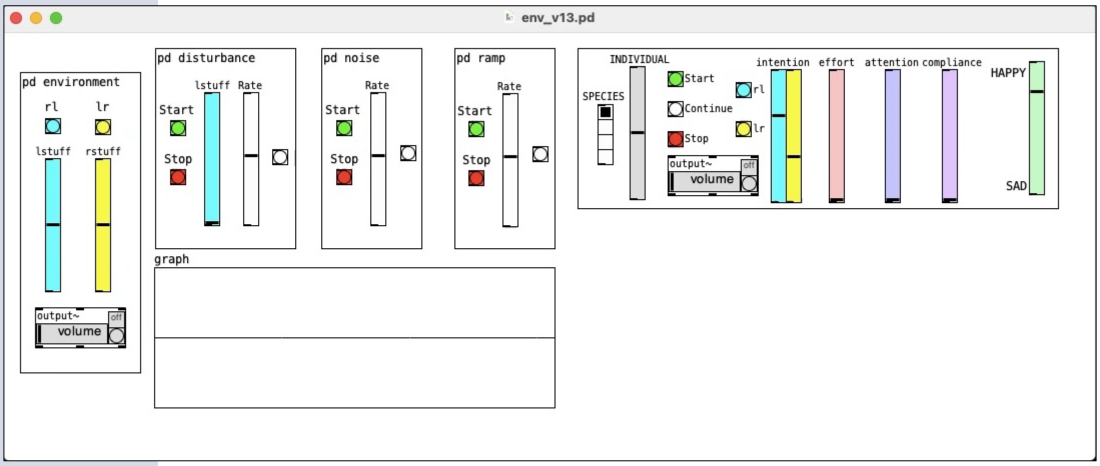
Demo-1: *Moving 'Stuff' Manually*



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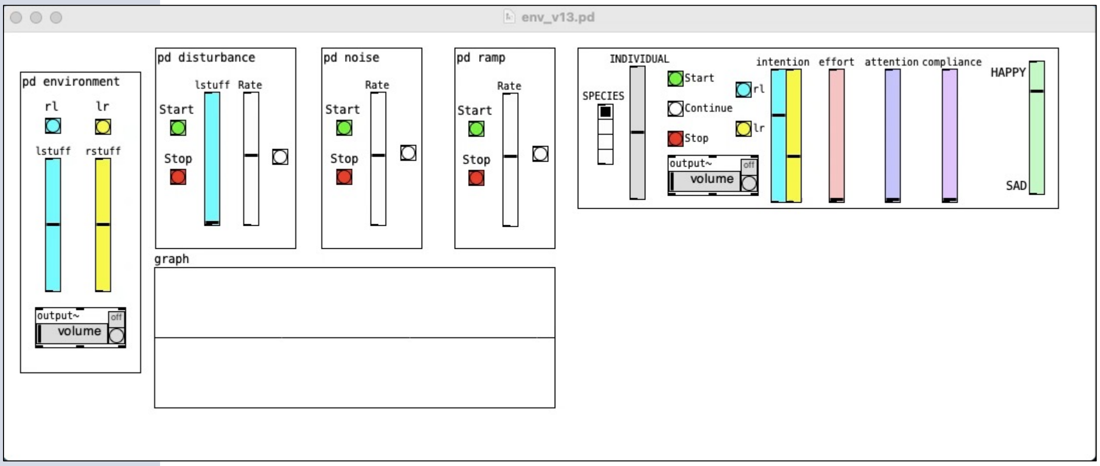
Demo-2: *Agent Moving 'Stuff'*



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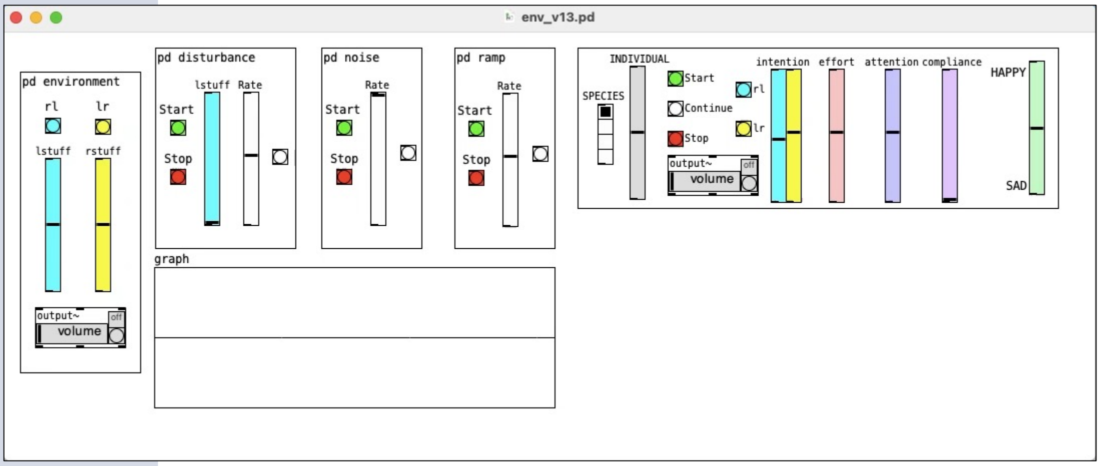
Demo-3: *Agent Resisting Noise*



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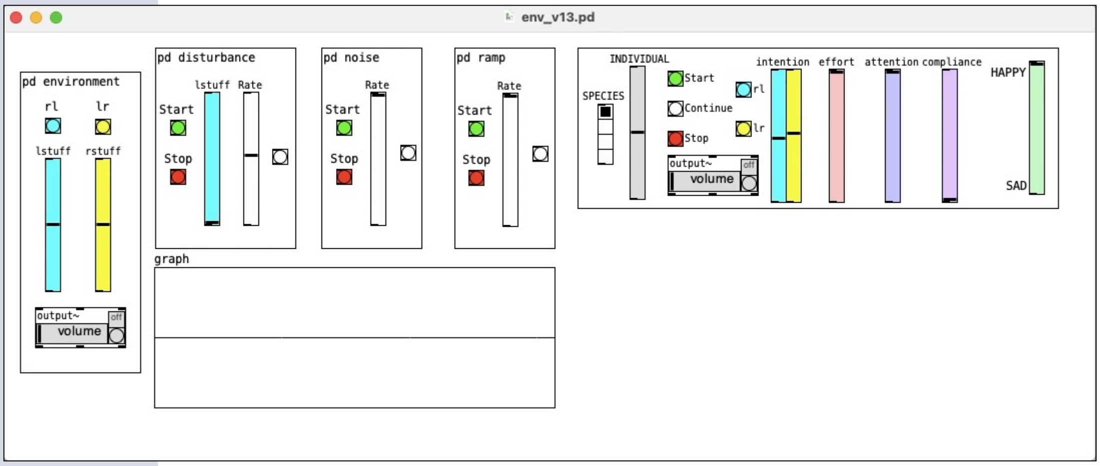
Demo-4: *Agent Resisting Ramp*



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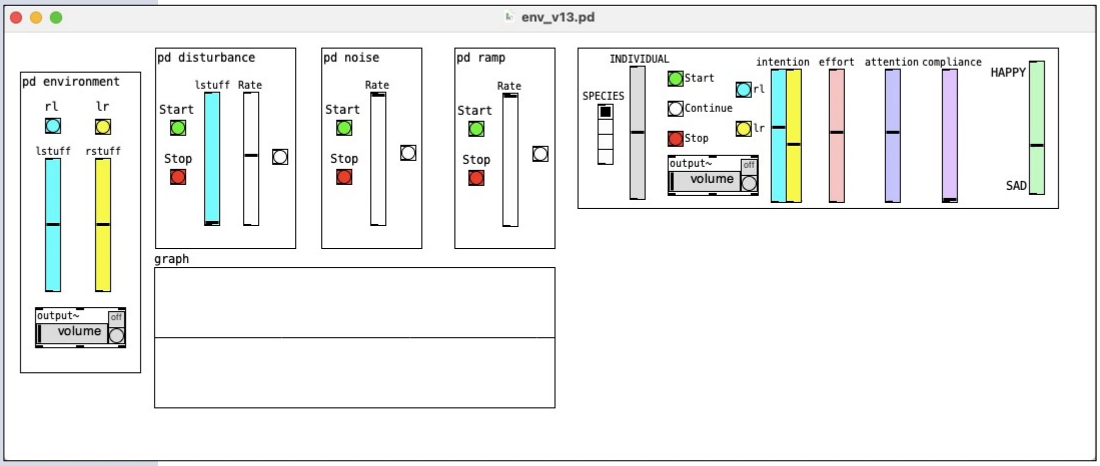
Demo-5: *Agent Complying with Ramp*



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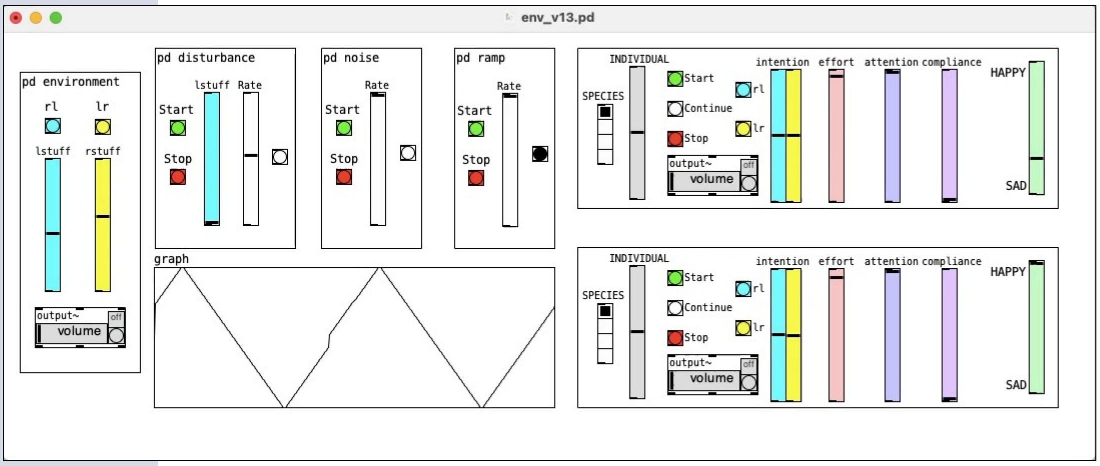
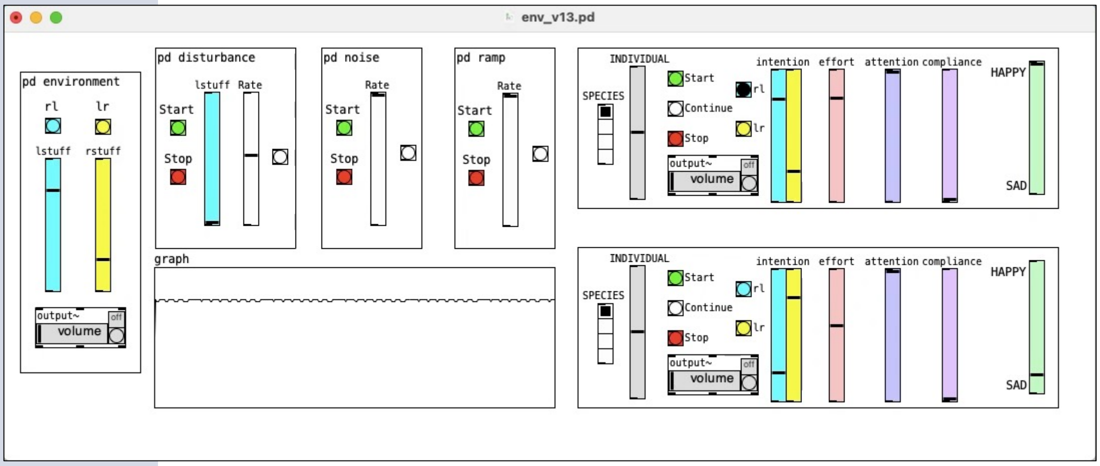
Demo-6: *Cooperation*



Demo-7: *Competition*



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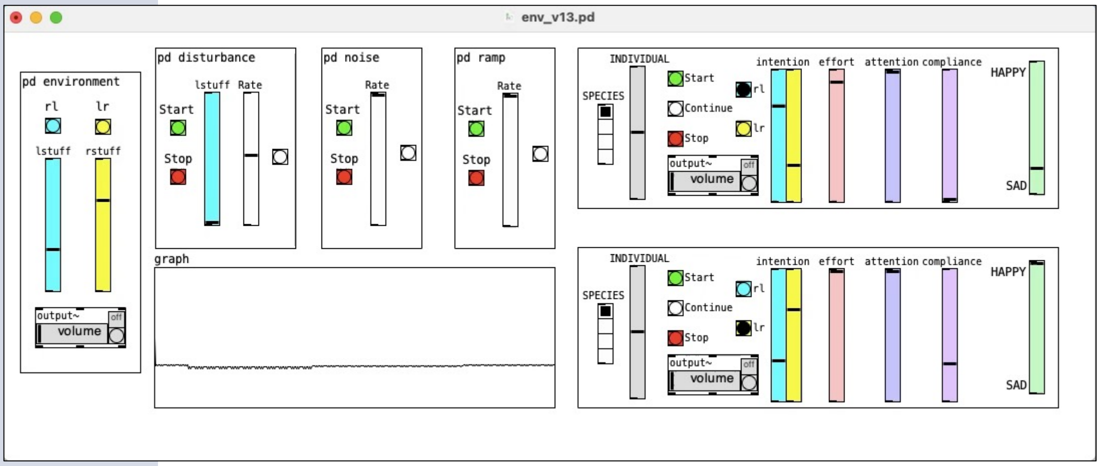
Demo-8: *Compliance*



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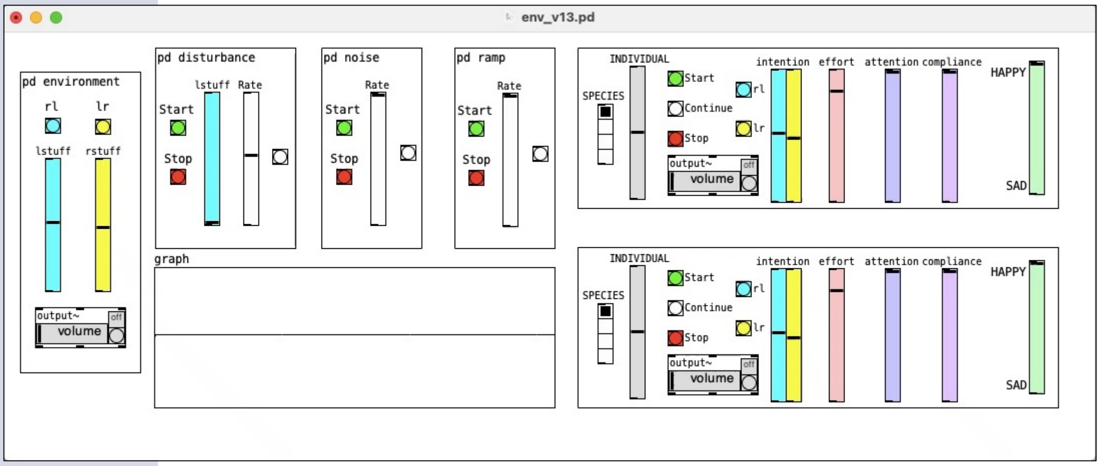
Demo-9: *Compromise*



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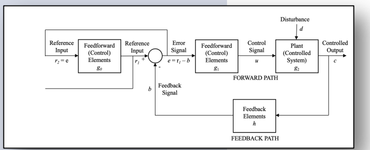
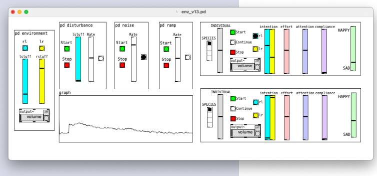
Implications

compliance → adaptation/learning → mimicry → intent recognition

- The compliant agent has learnt a hidden parameter of the dominant agent, and thus has acquired a model of the other agent (it has become the other agent!)
- I.e. a compliant agent acquires a generative model of perception (as in ‘predictive processing’)
- This is also known as ‘recognition-by-synthesis’ (and is a special case of ‘understanding-by-doing’, i.e. the same principle as ‘mirror neurons’)
- Bottom line: complying = explaining

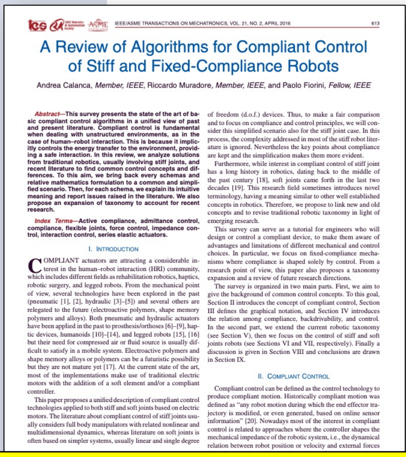
Summary and Conclusion



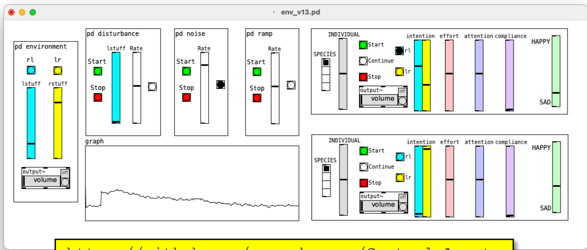


- Natural living systems are intrinsically ‘compliant’, whereas engineered systems are typically ‘stiff’
- This means that engineered systems either have to employ elastic components or have compliance programmed explicitly into their control architectures
- PCT is able to provide a general framework for modelling variable stiffness/compliance which may be applied to both natural and artificial systems
- Computer-based simulations have shown how PCT may be used to model key compliant behaviours, including interaction between agents with matched or mismatched compliance
- It has also been shown how the PCT perspective on compliance may be readily extended to encompass a form of adaptation/learning and the foundation of a generative/predictive model of perception

Where to Find Out More



Calanca, A., Muradore, R., & Fiorini, P. (2016). A Review of Algorithms for Compliant Control of Stiff and Fixed-Compliance Robots. *IEEE/ASME Trans. Mechatronics*, 21(2), 613–624.



https://github.com/rogerkmoore/Control-Agents

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Abstract

- In living systems - specifically, animals - movement is typically enacted by innervating one or more muscles to pull upon tendons, bones and soft tissues.
- In contrast, actuation in engineered systems is customarily implemented by means of electric motors actuating hard components such as gears, levers and wheels.
- This means that natural systems are intrinsically ‘compliant’ (that is, capable of adapting to a resistive force), whereas engineered systems are inherently ‘stiff’ and either have to employ soft components (such as springs or elastic structures) or have compliance programmed explicitly into their control architectures.
- The latter is particularly interesting from the perspective of Perceptual Control Theory (PCT), as PCT is able to provide a general framework for modelling variable stiffness/compliance which may be applied to both natural and artificial systems.
- This talk will illuminate this principle using computer-based simulations, and it will be shown how PCT may be used to model key compliant behaviours, including the consequences for interaction between agents with matched or mismatched compliance.
- In particular, it will be shown how dominant/submissive agents fare in cooperative and competitive scenarios, especially in terms of the motivational effort deployed towards solving a specific task.
- It will also be shown how the PCT perspective on compliance may be readily extended to encompass a form of adaptation/learning, which itself may be construed as a primitive form of predictive processing or, more interestingly, recognition-by-synthesis.
- In other words, while compliance may be characterised as an important feature of adaptive behaviour, it may also be seen as the foundation of perception.

- 30 mins = ~20 slides

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