on Neural Network Interpretations of OT

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Credits

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Introduction

- Optimality Theory
  - A symbolic theory from subsymbolic observations
- CV Theory: a toy domain
  - Simplified syllabification (skeletal subset of phonology)
  - Representations of forms and constraints are simple
  - Known linguistic typology
  - Productivity -- unbounded combinatorial structure
- CVNet
  - A neural network implementation

Optimality Theory

- Candidates
  - Input - Output structures
- Constraints
  - universal
  - violable
  - ranked
- Typology
  - re-ranking of constraints.

CV Theory

- Syllabification
- Candidates
  - Input Output

/$C^1V^2C^3C^4$/	[.C^1V^2.C^3**V**c^4.]	(epenthesis)
/paed + d/	[.paed.ed.]	
/$C^1V^2C^3$**C**^{4}/	[.$C^1V^2c^3$.]	(deletion)
/fish + s/	[fish]	

CV Theory

- CON: Constraints

PARSE	- for every element in the input there is a corresponding element in the output.
FILL_V	- every nucleus in the output has a corresponding element in the input.
FILL_C	- every consonant in the output has a corresponding element in the input.
ONSET	- every syllable nucleus has a preceding onset.
NOCODA	- there are no syllable Codas.

CV Theory

- GEN: “Inviolable” Constraints

IDENTITY	- each correspondence index may label at most one pairing
LINEARITY	- output segments maintain the order of their corresponding input segments
INTEGRITY	- each segment in the input corresponds to at most one segment in the output
UNIFORMITY	- each segment in the output corresponds to at most one segment in the input.

CV Theory

- GEN: Structural Constraints

IDENTITY$_{Output}$	- each output segment may be an onset, nucleus, or coda, but only one at a time.
NOGAPS	- no gaps between consecutive segments of an output string
NUCLEUS	- every onset must be followed by a nucleus and every coda must be preceded by a nucleus
CORRESPONDENCE	- no correspondence relation exists without both an input and output segment

/$C^1V^2C^3C^4$/ [.C^1V^2.C^3**V**c^4.] (epenthesis)

/paed + d/ [.paed.ed.]

/paed + d/ /$C^1V^2C^3C^4$/	NoCODA	FILLv	PARSE
[.C^1V^2.C^3**V**c^4.] [.paed.ed.]		*	
[.C^1V^2.C^3V.]		*	*!
[.$C^1V^2c^3$.]	*!		*

/$C^1V^2C^3C^4$/ [.C^1V^2.C^3**V**c^4.] (deletion)

/paed + d/ [.paed.ed.]

/paed + d/ /$C^1V^2C^3C^4$/	FILLv	NoCODA	PARSE
[.C^1V^2.C^3**V**c^4.] [.paed.ed.]	*!		
[.C^1V^2.C^3V.]	*		*!
[.$C^1V^2c^3$.]		*	*

CV Theory: Typology

PARSE >> FILL$_C$ >> **FILL$_V$** >> **NOCODA** >> ONSET

no deletion. no epenthesis.

/$V^1C^2C^3V^4$/ [.V^1c.C^2V^4.]

/ipso/ [.ip.so.]

PARSE >> FILL$_C$ >> **NOCODA** >> **FILL$_V$** >> ONSET

no deletion. epenthesize vowels to avoid codas.

/$V^1C^2C^3V^4$/ [.V^1.C^2**V**.C^3V^4.]

/ipso/ [.i.pu.so.]

CV Theory: Typology

FILL$_V$ >> PARSE >> ONSET >> FILL$_C$ >> NOCODA

no vowel epenthesis.

/$C^1V^2C^3C^4$/ [.C^1V^2.c^3]

/fish+s/ [.fish.]

FILL$_C$ >> PARSE >> ONSET >> FILL$_V$ >> NOCODA

vowel epenthesis, but no consonant epenthesis.

/$C^1V^2C^3C^4$/ [.C^1V^2.C^3Vc^4.]

/fish+s/ [.fi.shes.]

CV Theory: Typology

PARSE >> **FILL$_V$** >> **NOCODA** >> ONSET >> FILL$_C$

Codas allowed.

/$C^1V^2C^3$/ [.$C^1V^2c^3$.]

/cat/ [.cat.]

PARSE >> **NOCODA** >> **FILL$_V$** >> ONSET >> FILL$_C$

Codas not allowed.

/$C^1V^2C^3$/ [.C^1V^2.C^3V.]

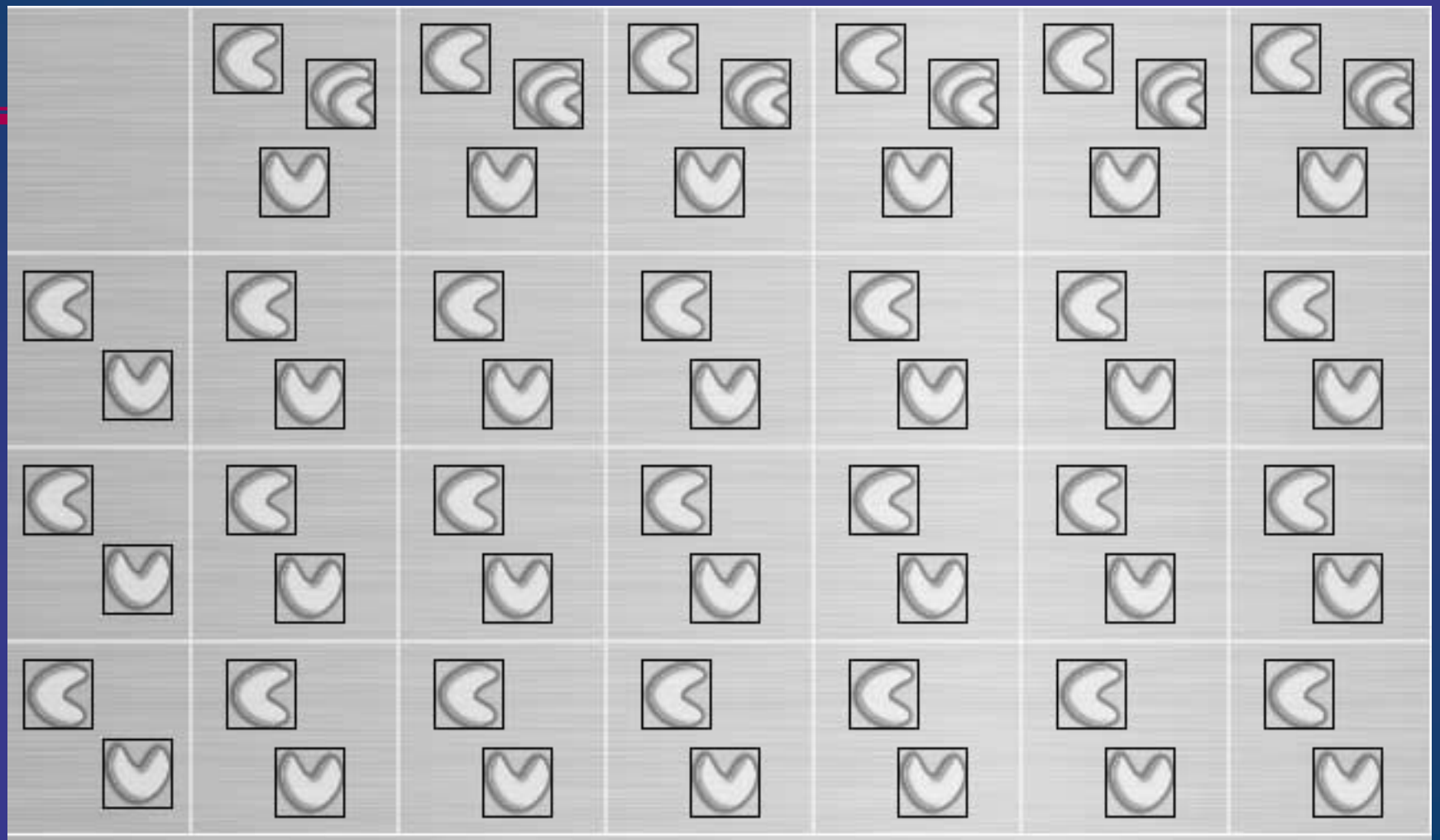
/cat/ [.ca.tu.]

CV Net

- Harmony network
  (Boltzman machine / Hopfield net)
- Localist representations
- Input units, output units, correspondence units
- No hidden units
- Each constraint is a set of (tied) symmetric weights + biases.

Ouput Units

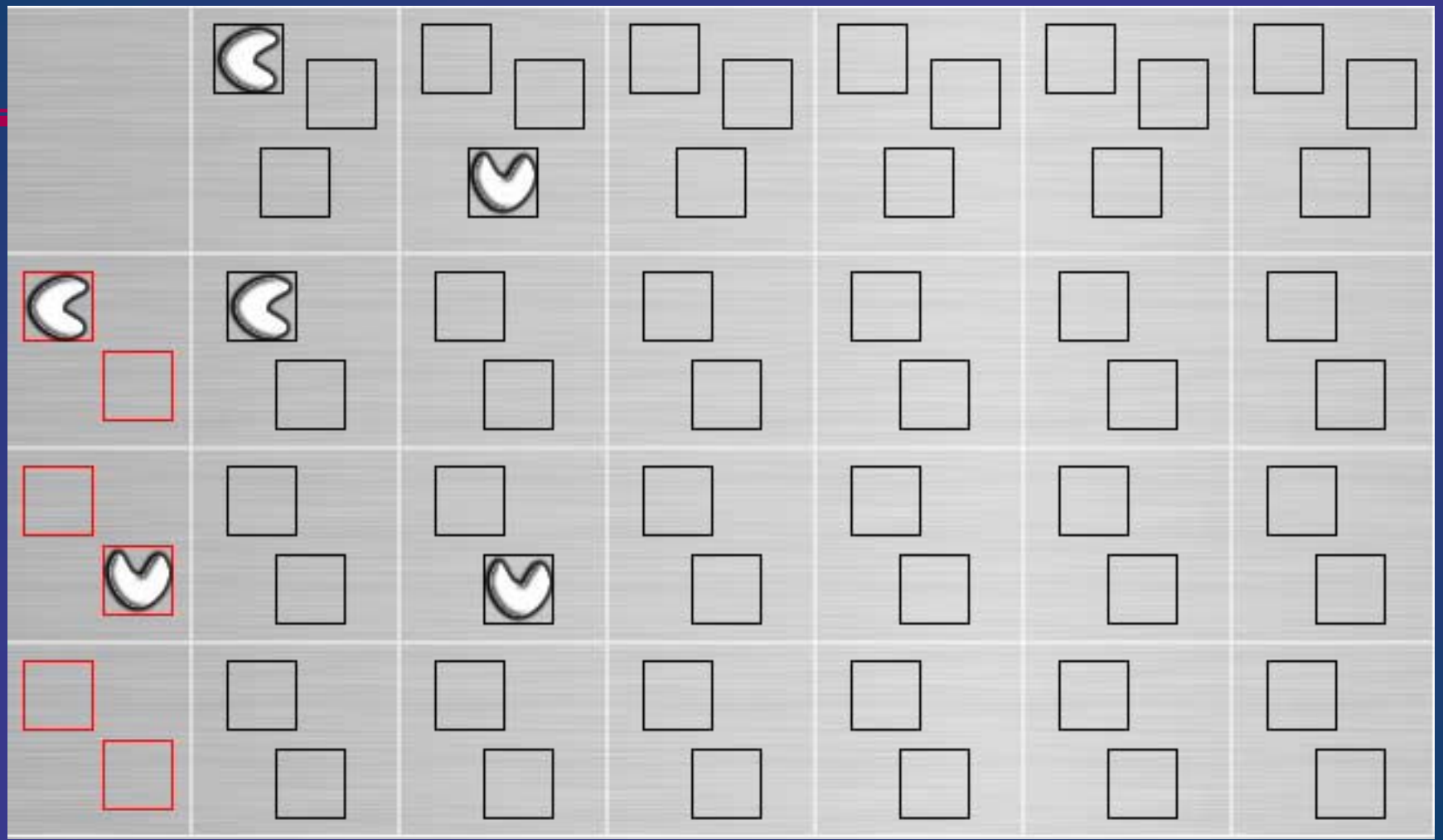
Input Units



Correspondence Units

/C^1V^2/ -> [.C^1V^2.]

Ouput Units



Input Units

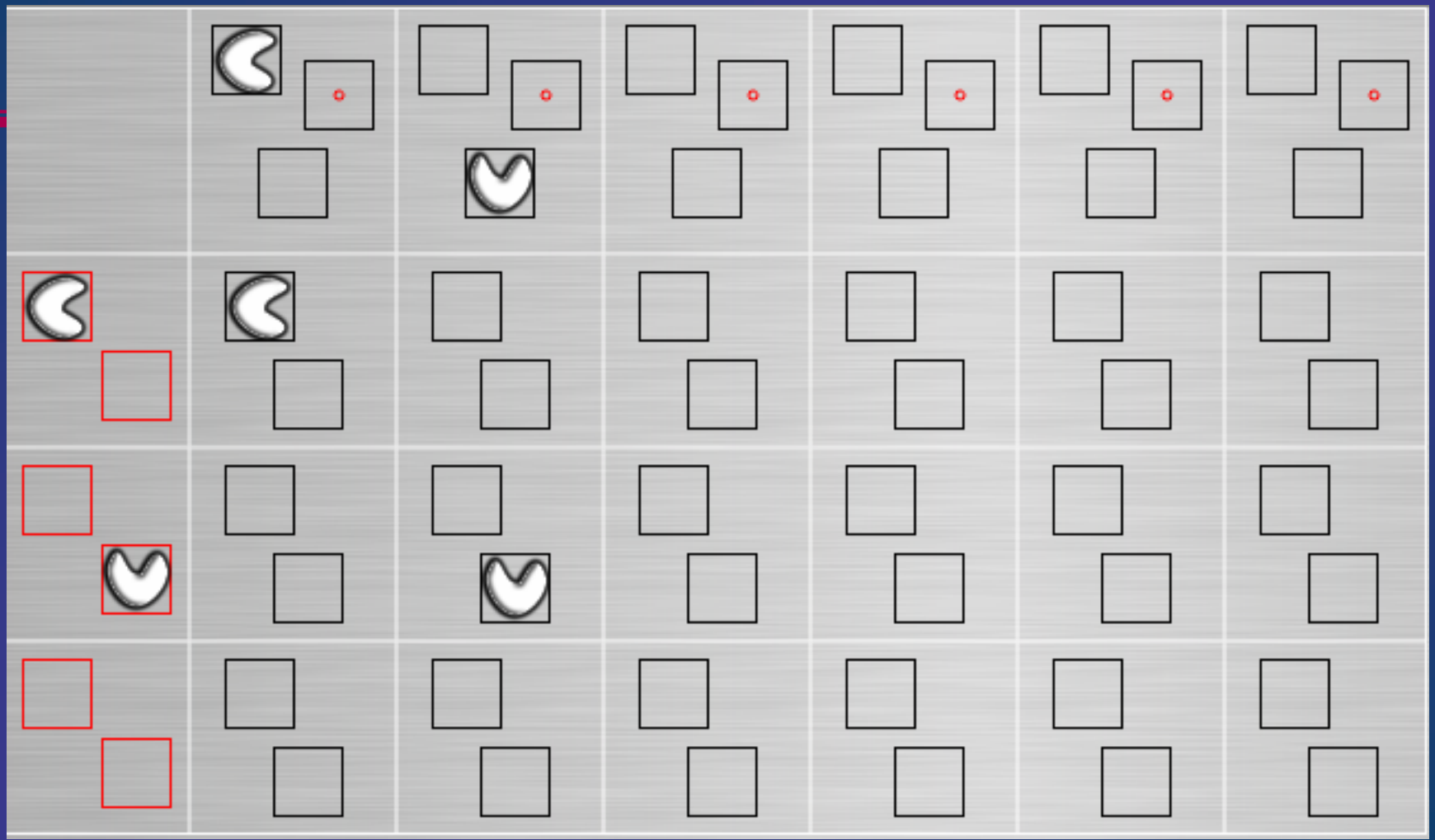
Correspondence Units

CV Net: Constraints

- Each constraint is a set of (tied) symmetric weights + biases.

NoCODA

Ouput Units

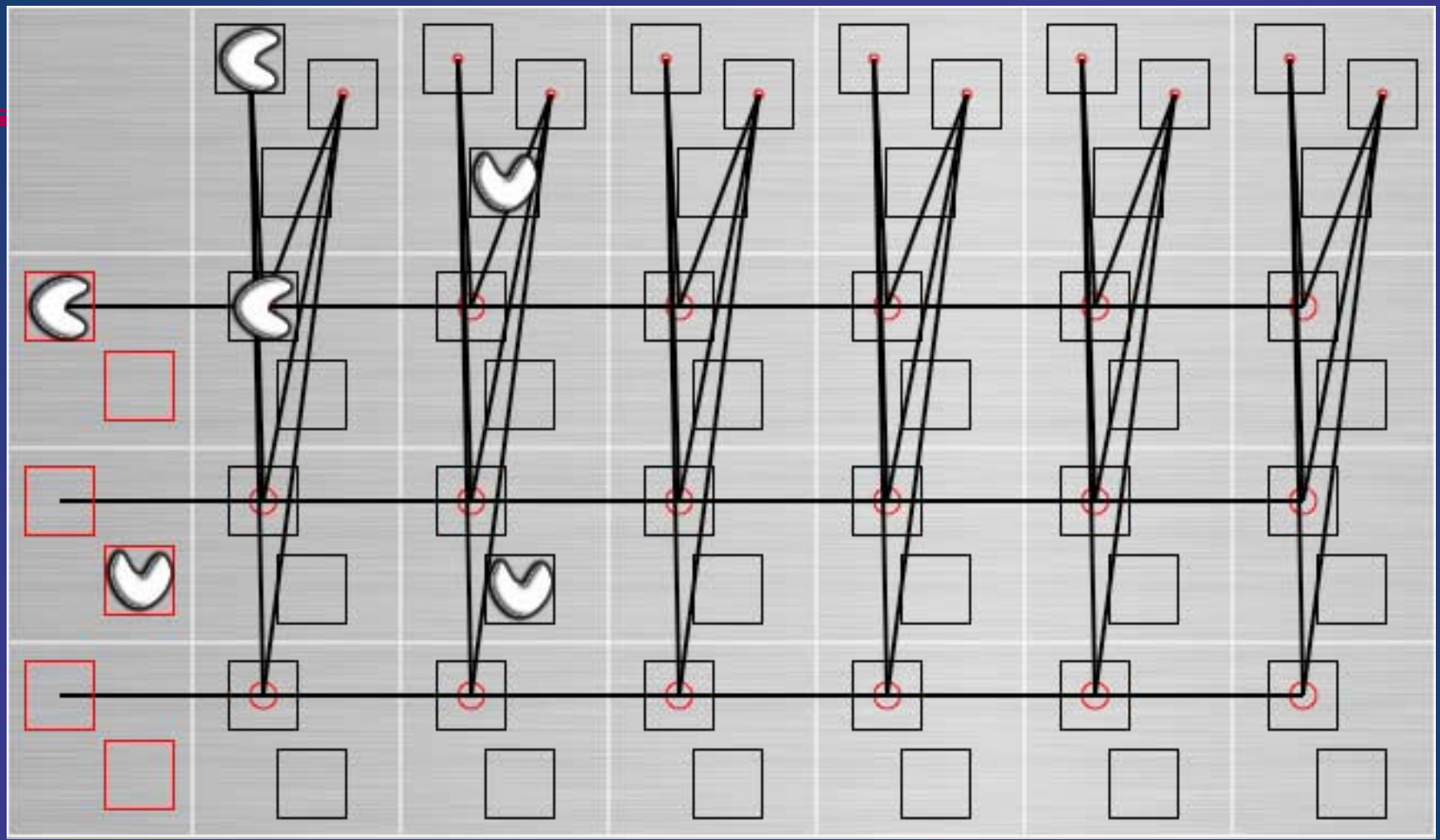


Input Units

Correspondence Units

FILLc

Ouput Units



Input Units

Correspondence Units

CV Net: Violations & Harmony

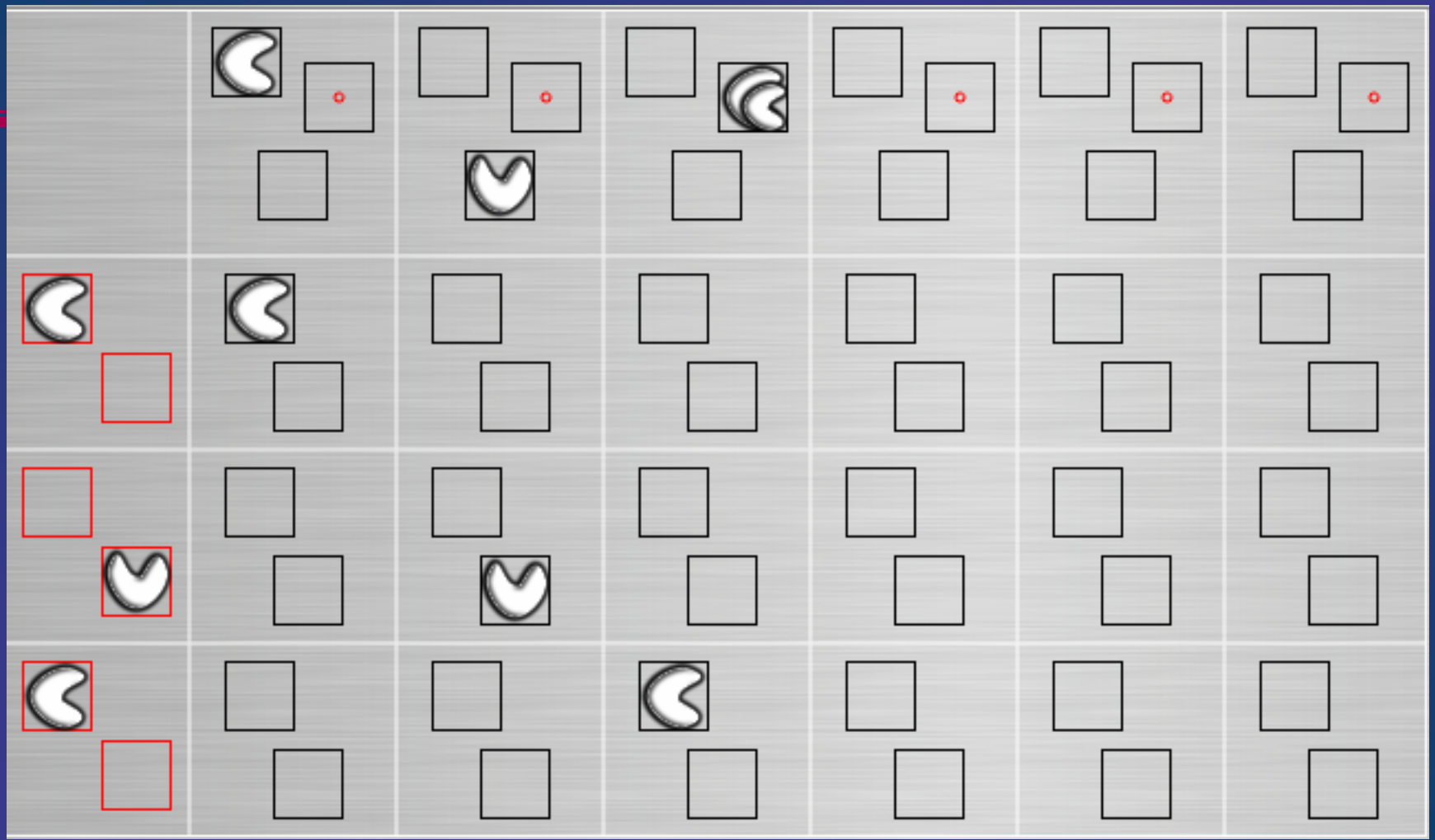
- Harmony is a measure of the extent to which a network state obeys the (local) constraints implied by a weight matrix.

$$H_i(a) = \tfrac{1}{2} \sum_{\varphi,\psi=1}^{N} c^{i}_{\varphi,\psi} a_\varphi a_\psi$$

- The number of violations of a constraint *i* correspond to the negative integer value of the harmony of the network w.r.t. that constraint H_i

FILLc

Ouput Units

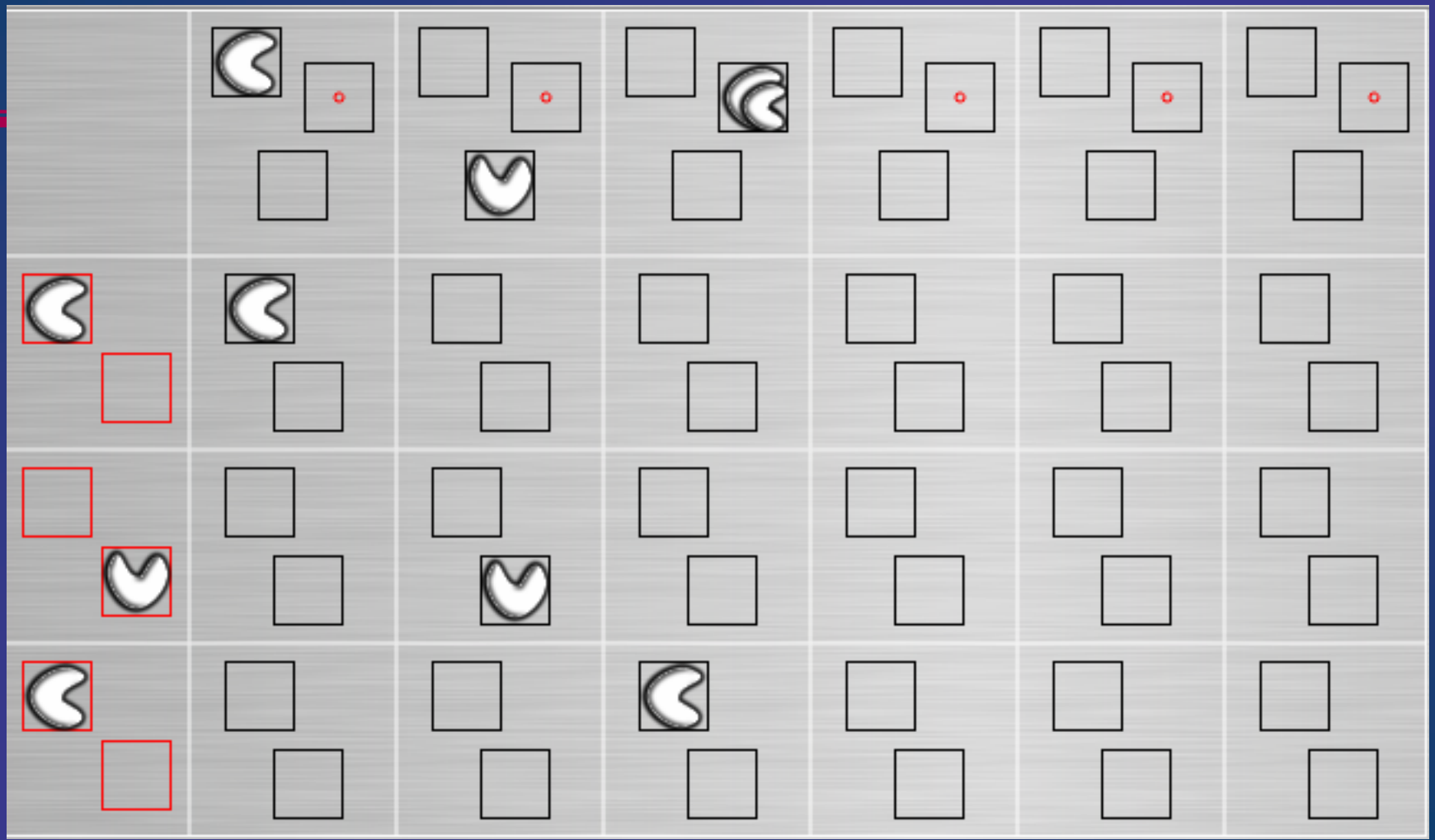


Input Units

Correspondence Units

NoCODA violation

Ouput Units



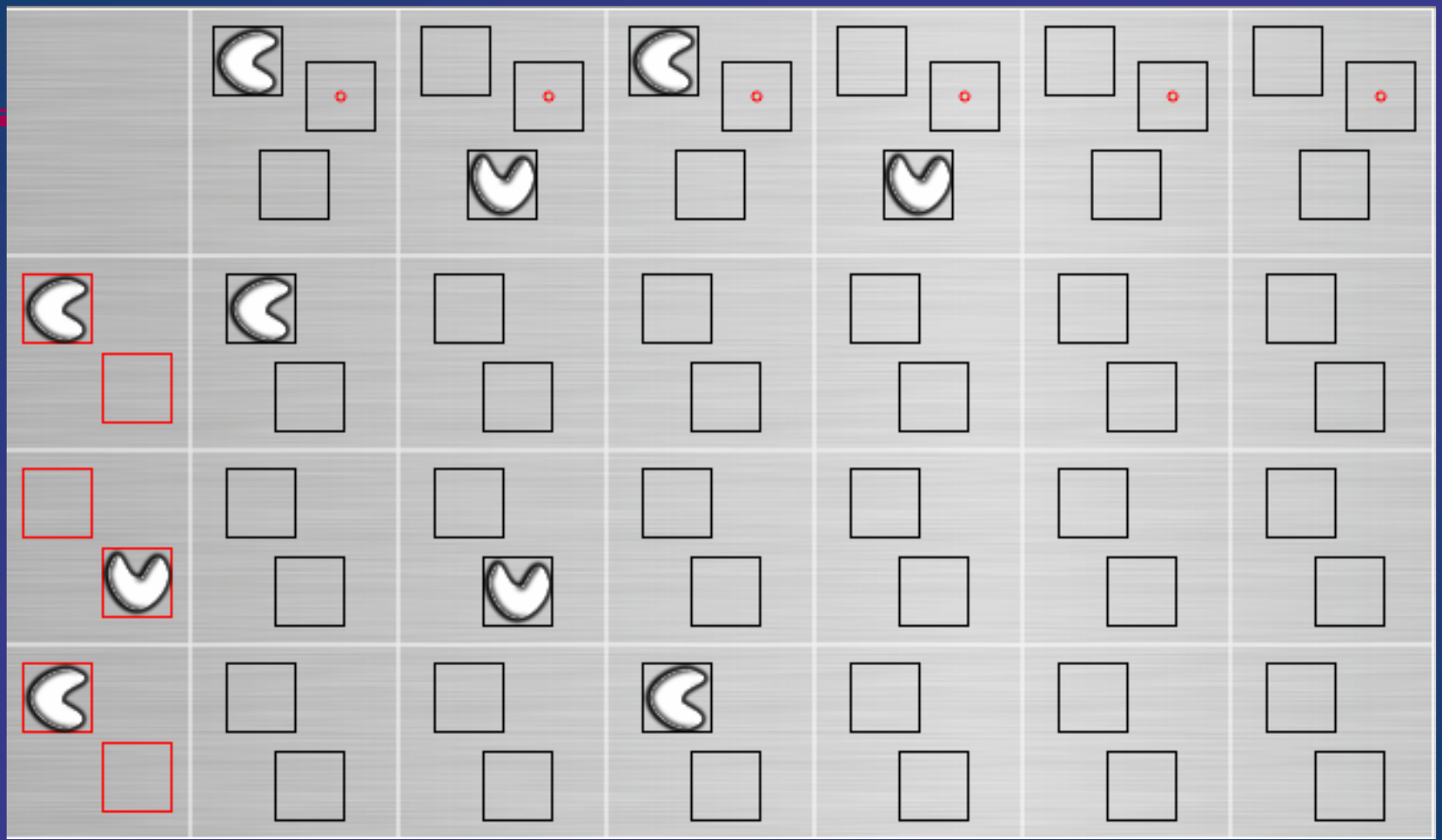
Input Units

Correspondence Units

NoCODA no violation

Ouput Units

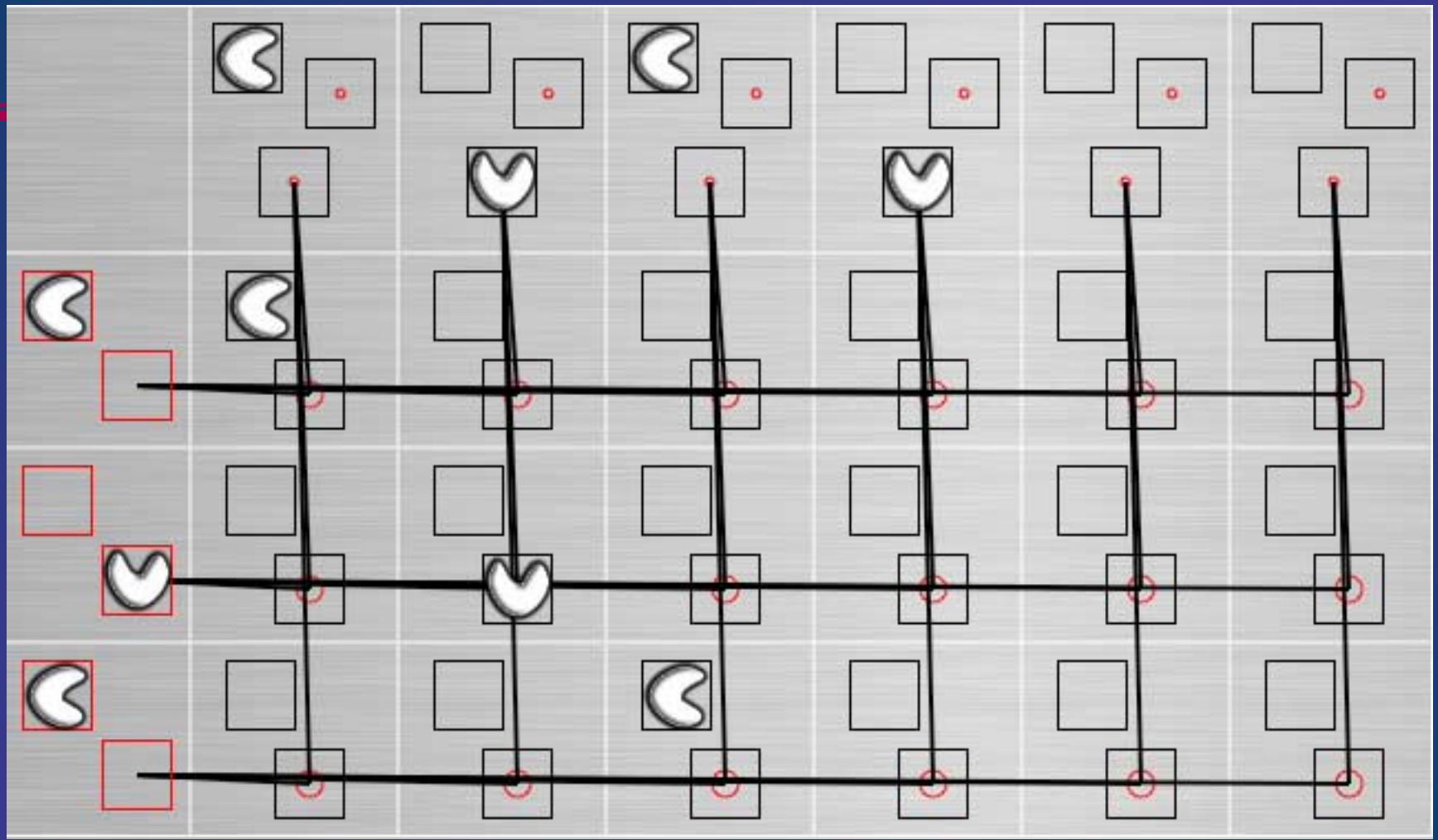
Input Units



Correspondence Units

FILLv violation

Ouput Units



Input Units

Correspondence Units

CV Net: Violations & Harmony

- The network activation state that yields the (global) maximum harmony value corresponds to the optimal candidate for a given input.

CV Net: Strict Dominance

- For constraints A >> B, strict dominance implies that no matter how bad a candidate form is on B, if it is better than all other forms on A, it is optimal.
- Harmony is a real valued function.
- If the difference in harmony values across constraints is exponential, strict dominance obtains.
  - Must this be the case?

CV Net: Processing

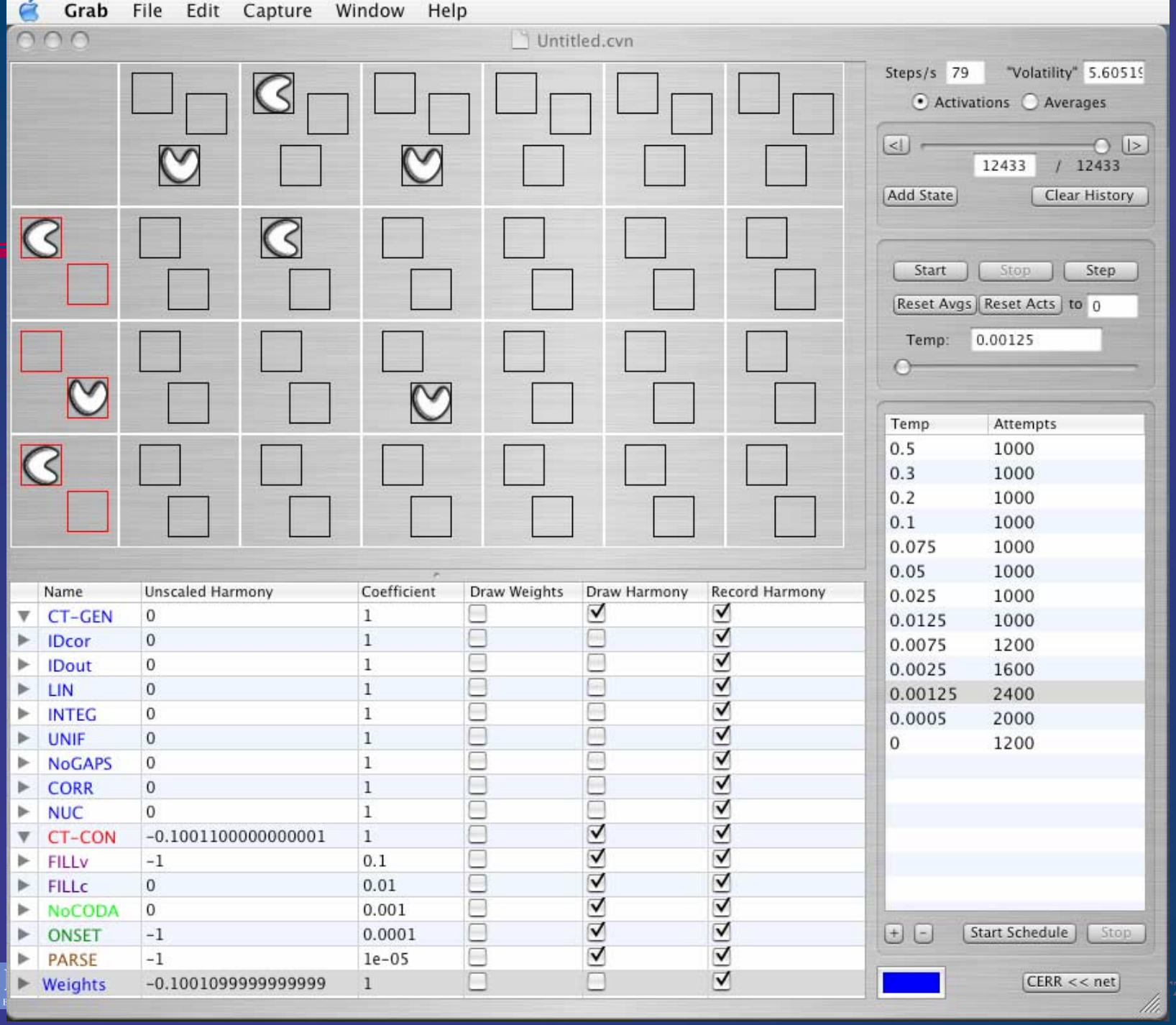
- Processing occurs as in an ordinary Boltzman machine -- through simulated annealing.
- Updates:
  - A unit is selected at random
  - If the net input to the unit + a random variable whose range depends on the “network temperature” is positive, the unit fires. Otherwise, it does not.
- This proceeds through stages where the temperature is gradually lowered.

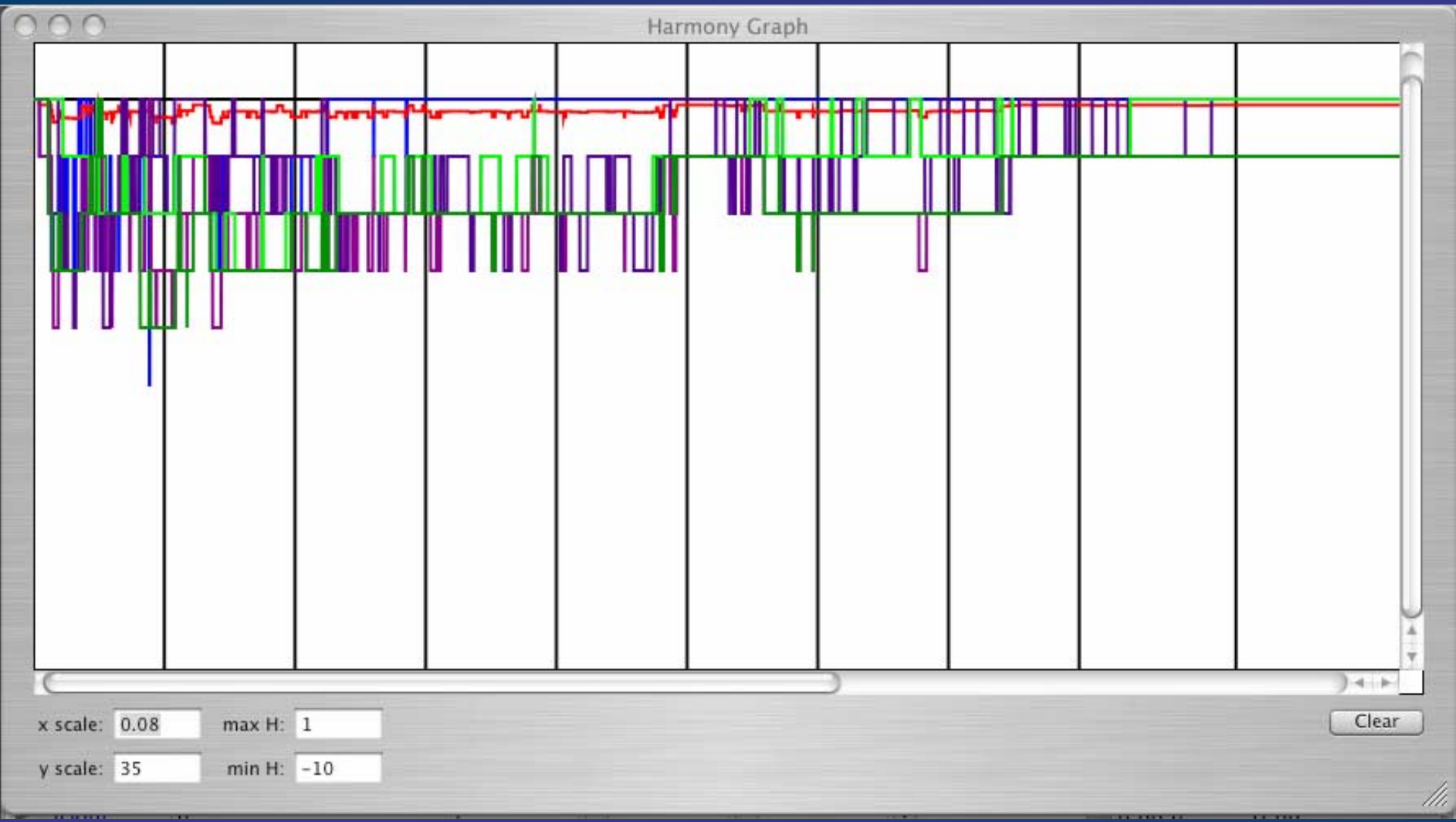
CV Net: Processing Problems

- Local Harmony maxima
- CON constraints are supposed to help the network choose the correct local maximum. (the global one).
- But the GEN constraints, high ranked, make it very difficult for the network to get from one GEN-respecting state to another.
- Even though the global harmony maximum is the optimal candidate, it is not necessarily easy for the network to find.
  - With these activation dynamics.

CV Net: Learning

- Boltzman Machine Learning Algorithm.
  - Calculate the network's best guess for a clamped input.
  - Compare to the correct output for a clamped input.
  - Adjust connection strengths to make the correct output more likely.
- Boltzman Machine Learning Algorithm w.r.t. Constraints (as sets of tied weights) as opposed to individual weights.
  - Corresponds to symbolic constraint demotion.
  - If the expected values of activations can be approximated.


Grab File Edit Capture Window Help
Untitled.cvn
Steps/s 79
"Volatility" 5.60519
Activations
Averages
12433 / 12433
Add State
Clear History
Start
Stop
Step
Reset Avgs
Reset Acts
to 0
Temp: 0.00125
Temp
Attempts
0.5 1000
0.3 1000
0.2 1000
0.1 1000
0.075 1000
0.05 1000
0.025 1000
0.0125 1000
0.0075 1200
0.0025 1600
0.00125 2400
0.0005 2000
0 1200
Start Schedule
Stop
CERR << net
Name
Unscaled Harmony
Coefficient
Draw Weights
Draw Harmony
Record Harmony
CT-GEN 0 1
IDcor 0 1
IDout 0 1
LIN 0 1
INTEG 0 1
UNIF 0 1
NoGAPS 0 1
CORR 0 1
NUC 0 1
CT-CON -0.1001100000000001 1
FILLv -1 0.1
FILLc 0 0.01
NoCODA 0 0.001
ONSET -1 0.0001
PARSE -1 1e-05
Weights -0.1001099999999999 1


Harmony Graph
x scale:
0.08
max H:
1
y scale:
35
min H:
-10
Clear

Thank you