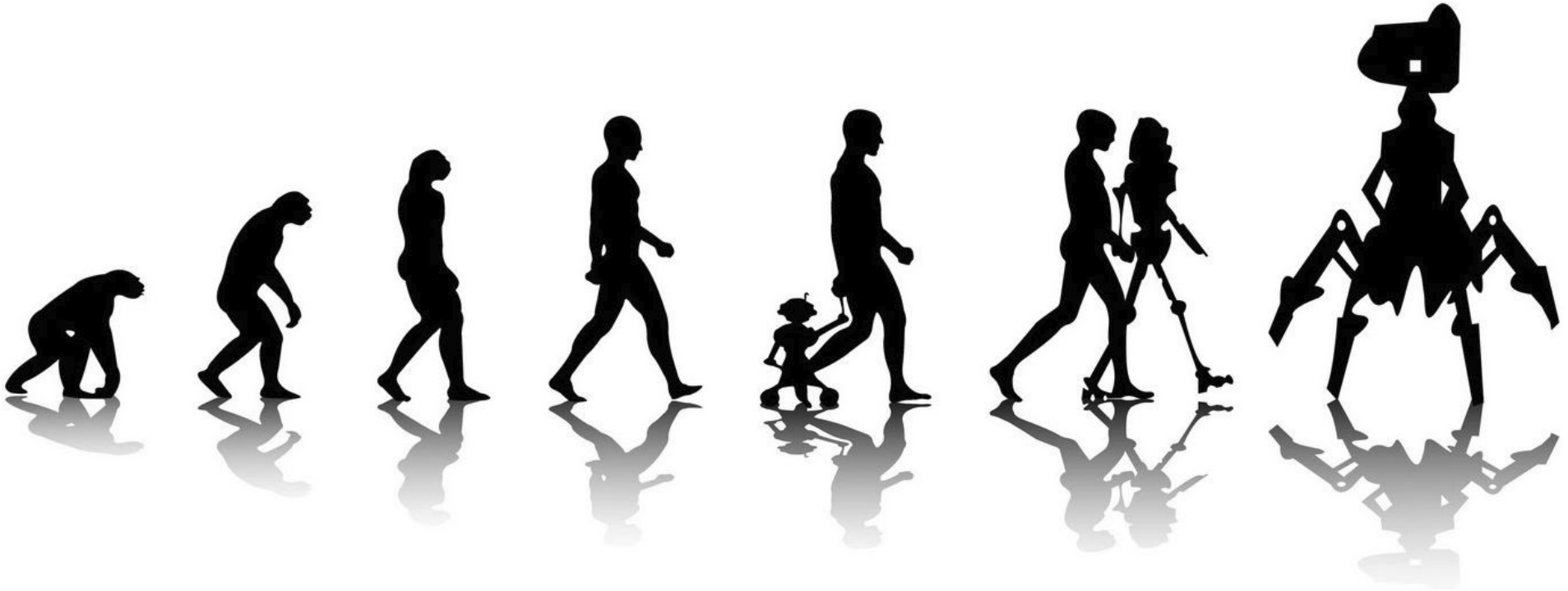


Modern Robotics: Evolutionary Robotics

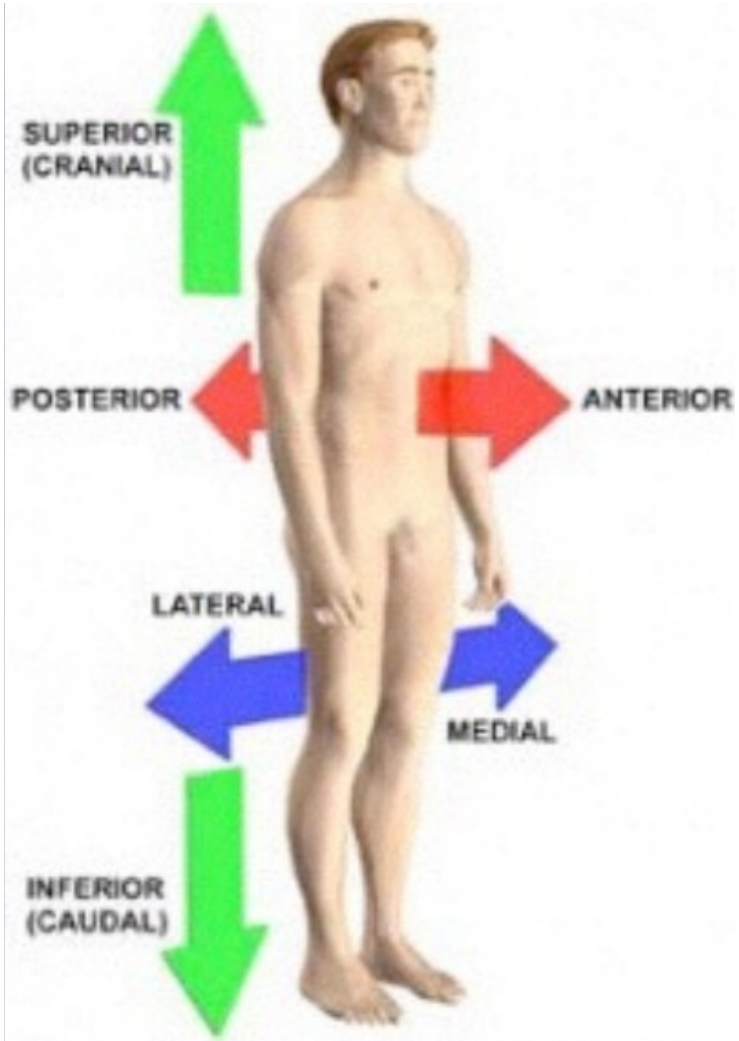
COSC 4560 / COSC 5560

Professor Cheney

2/16/18

The Evolution of Complex Patterns

“Regularity without Development”


SUPERIOR
(CRANIAL)
POSTERIOR
ANTERIOR
LATERAL
MEDIAL
INFERIOR
(CAUDAL)

Images are generated procedurally by symbolic Lisp expressions:

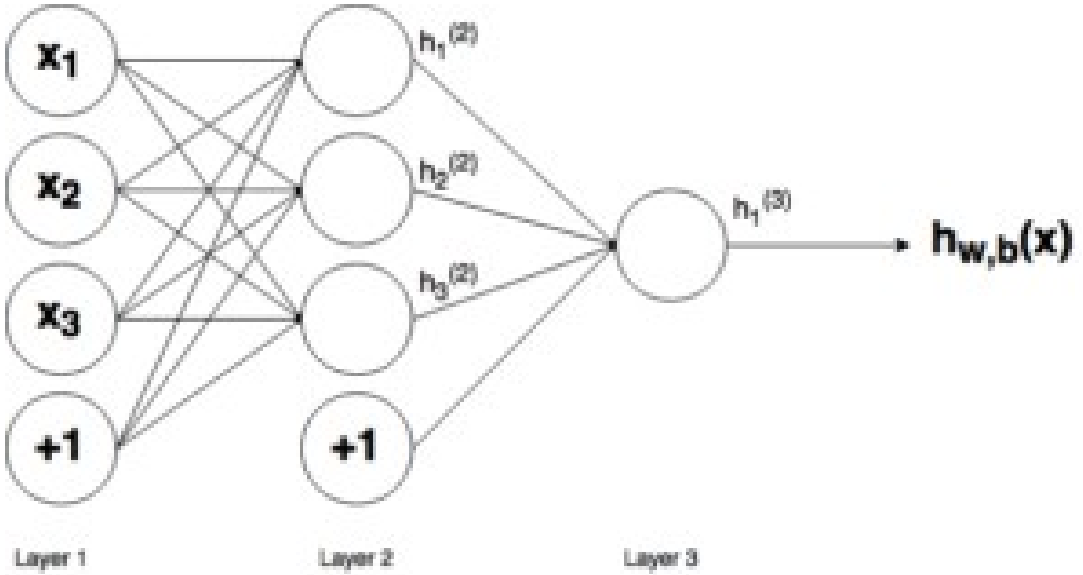
Color <= F(x,y)

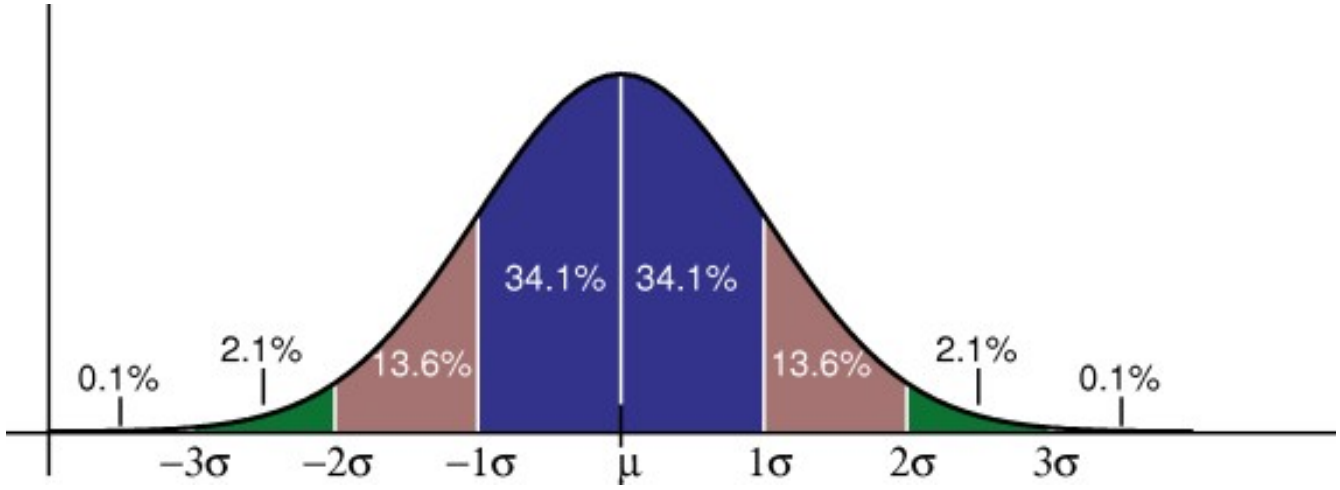
Phenotype:
(Image)

Genotype:
(Lisp code)

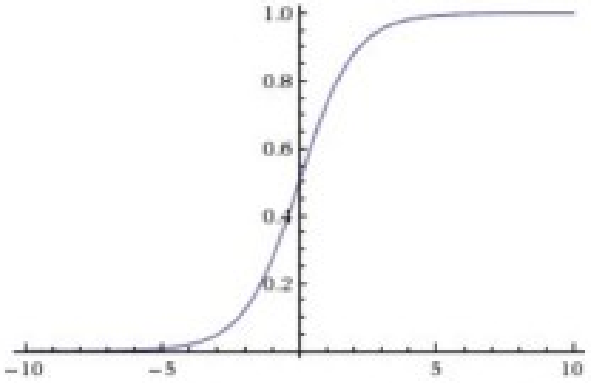
```
(round (log (+ y (color-grad (round (+ (abs (round (log
(+ y (color-grad (round (+ y (log (invert y) 15.5)) x) 3.1
1.86 #(0.95 0.7 0.59) 1.35)) 0.19) x)) (log (invert y) 15.5))
x) 3.1 1.9 #(0.95 0.7 0.35) 1.35)) 0.19) x)
```

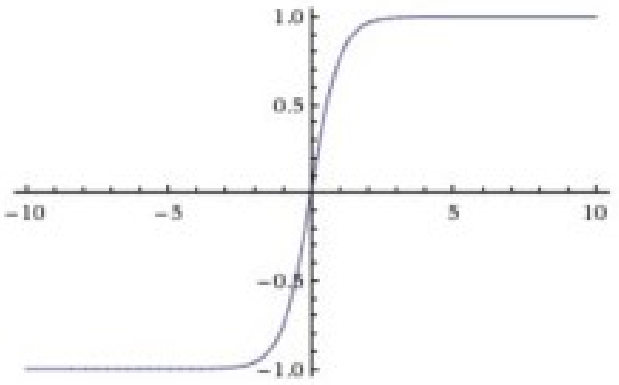
Compositional Pattern Producing Networks (CPPN)

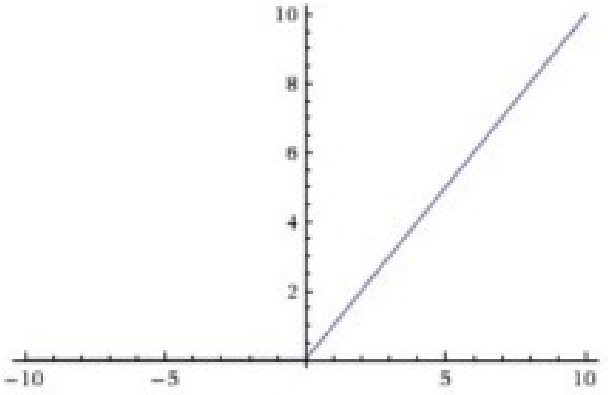

x1
x2
x3
+1
h1(2)
h2(2)
h3(2)
+1
h1(3)
hw,b(x)
Layer 1
Layer 2
Layer 3


0.1%
2.1%
13.6%
34.1%
34.1%
13.6%
2.1%
0.1%
−3σ
−2σ
−1σ
μ
1σ
2σ
3σ

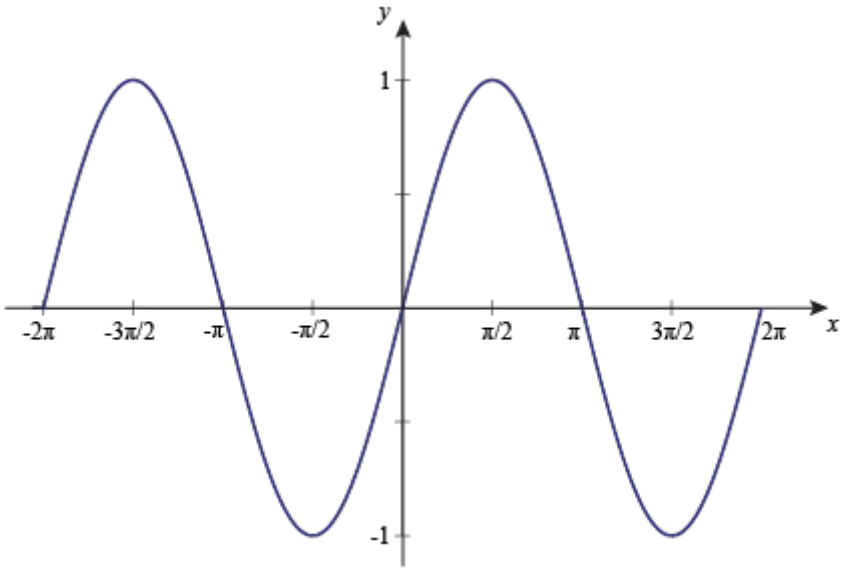
activation functions





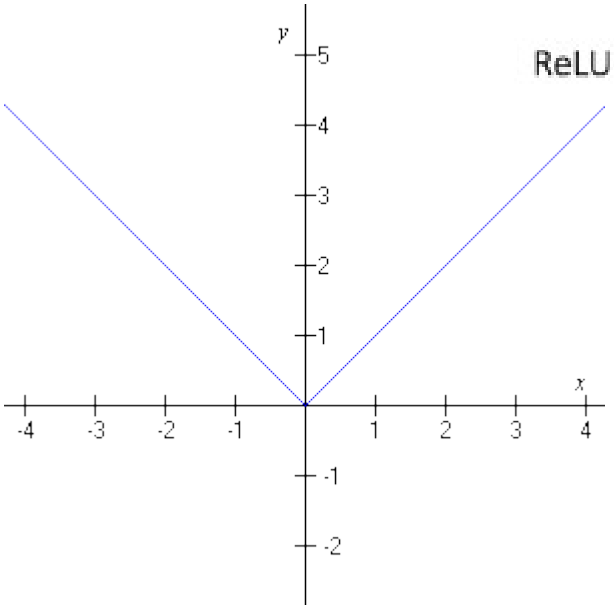


Sigmoid



tanh

ReLU



Genetic Operators:

Mutate Weight
Add Edge
Remove Edge

Add Node
Remove Node
Modify Activation Function

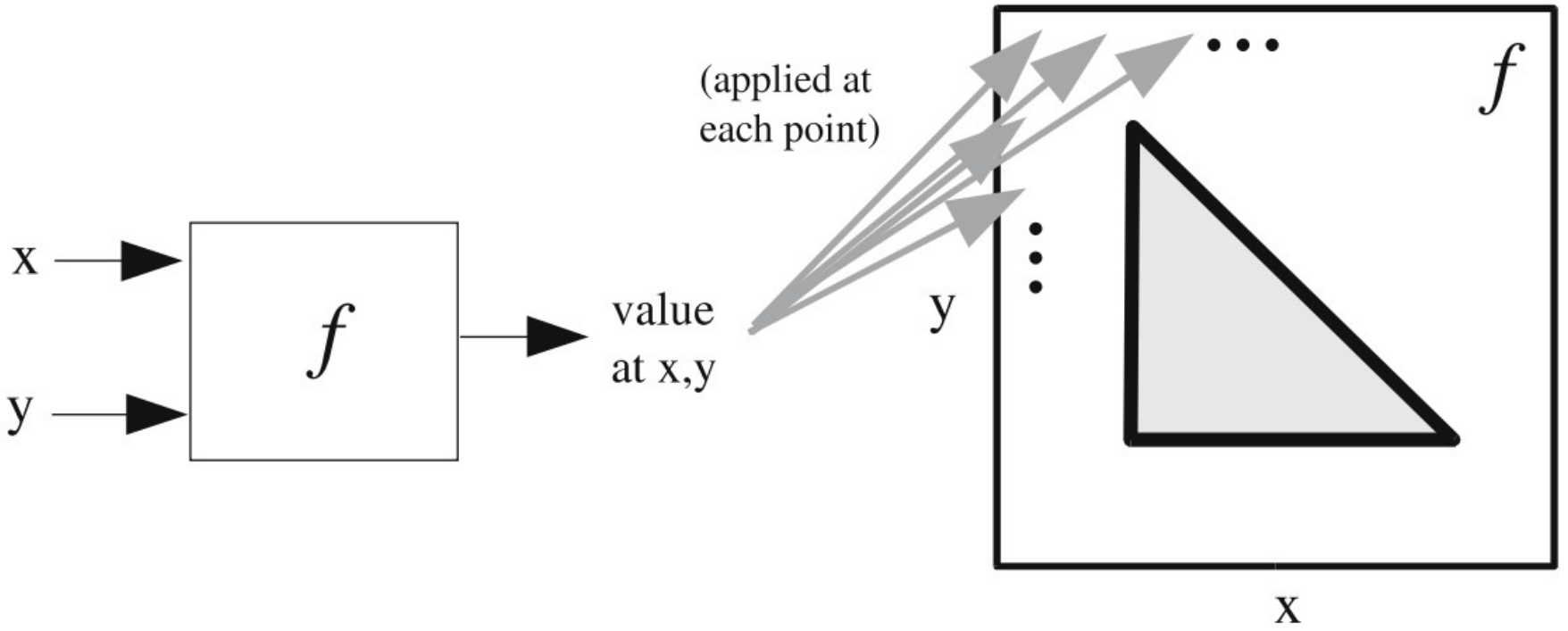
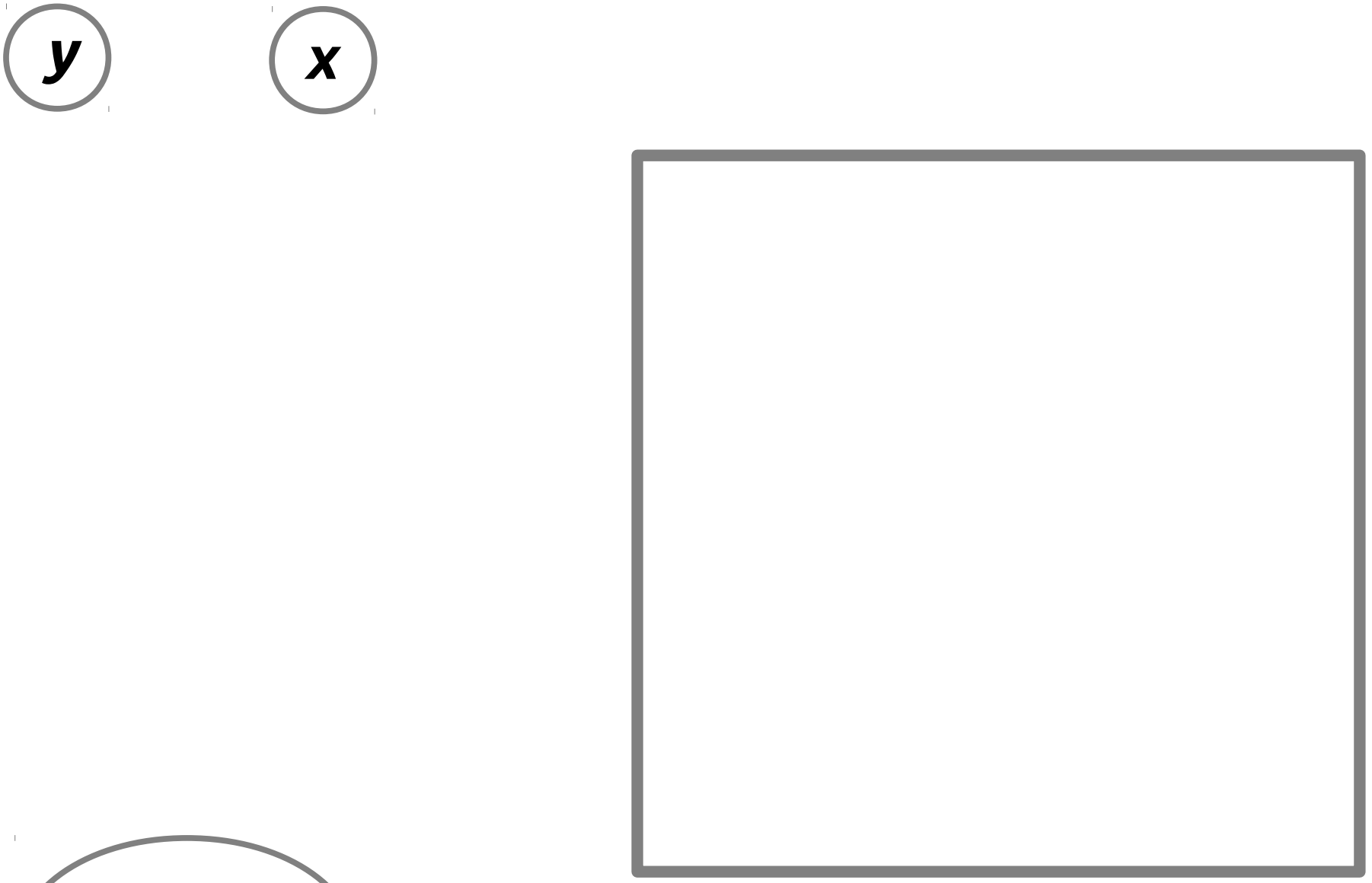


Fig. 1 *A function produces a phenotype*. The function *f* takes arguments *x* and *y*, which are coordinates in a two-dimensional space. When all the coordinates are drawn with an intensity corresponding to the output of *f* at that coordinate, the result is a pattern, which can be conceived as a phenotype whose genotype is *f*. In this example, *f* produces a triangular phenotype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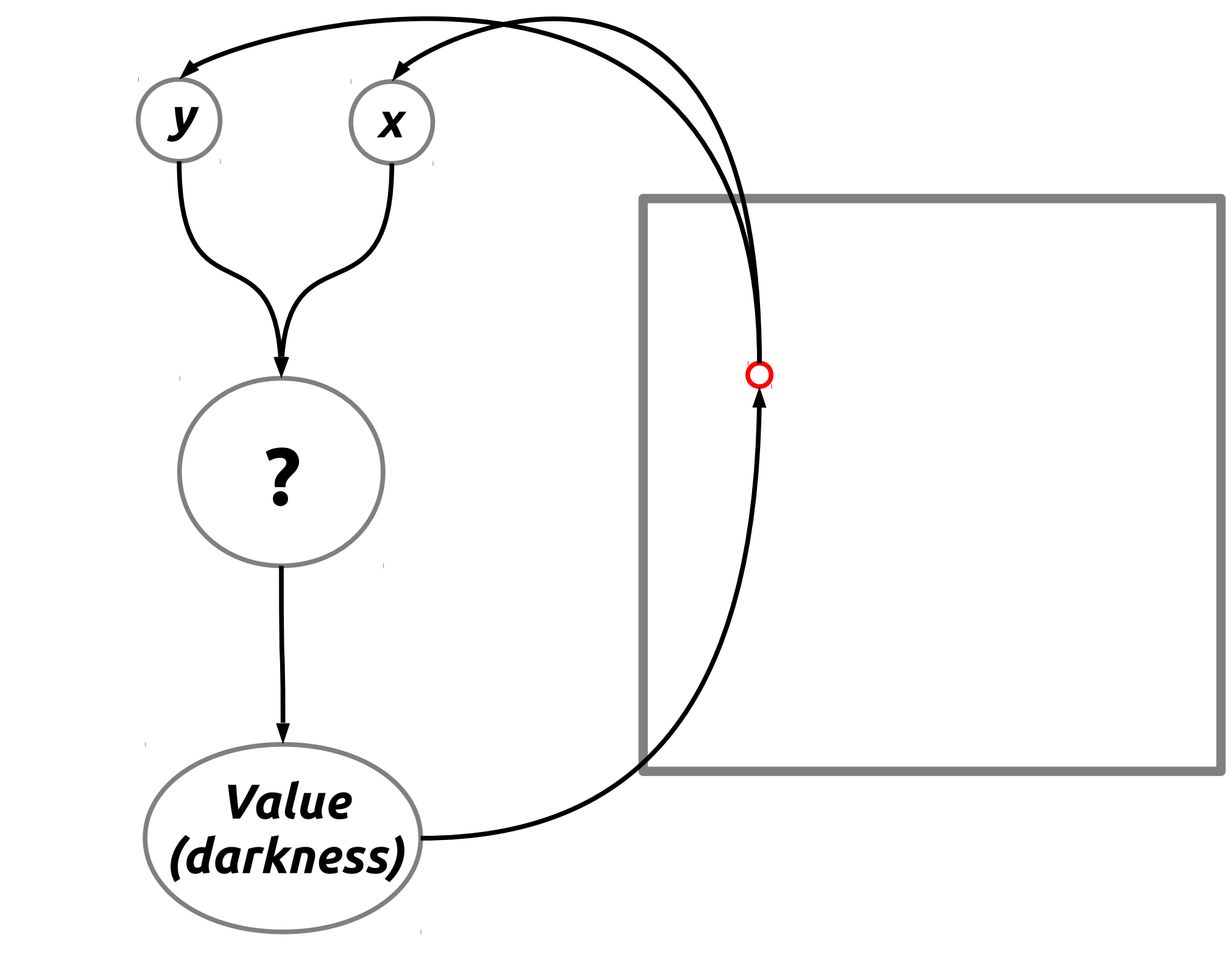
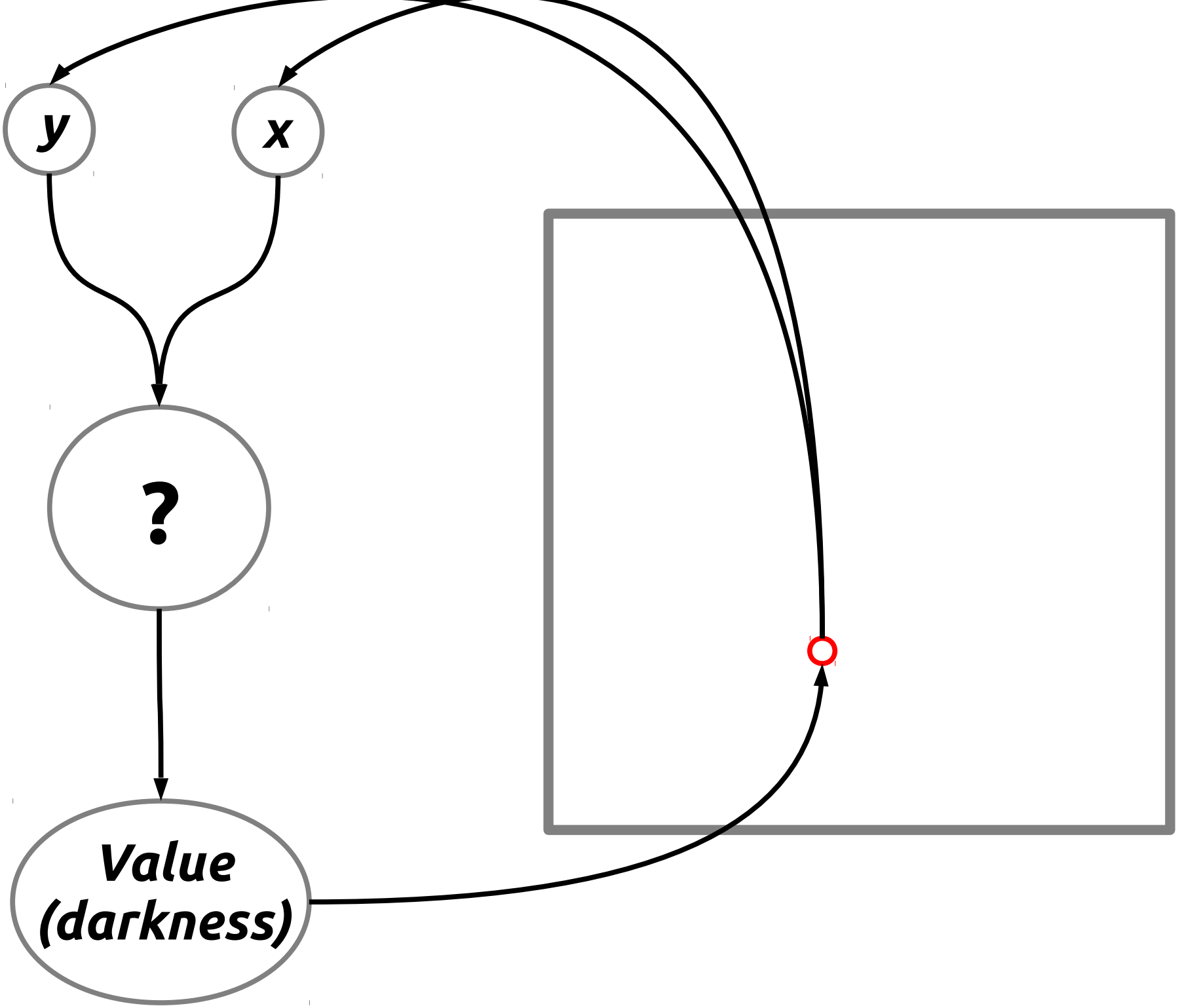
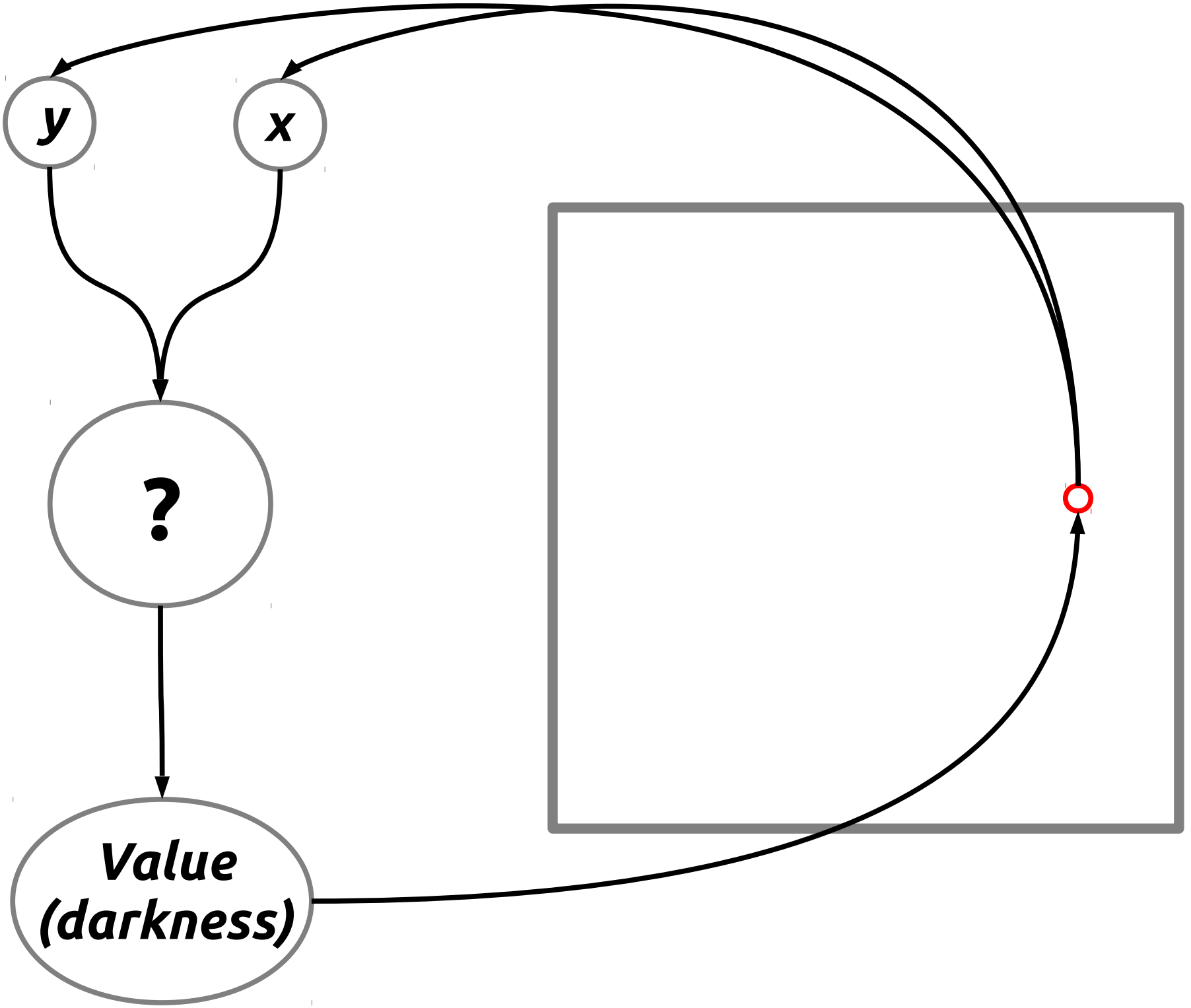
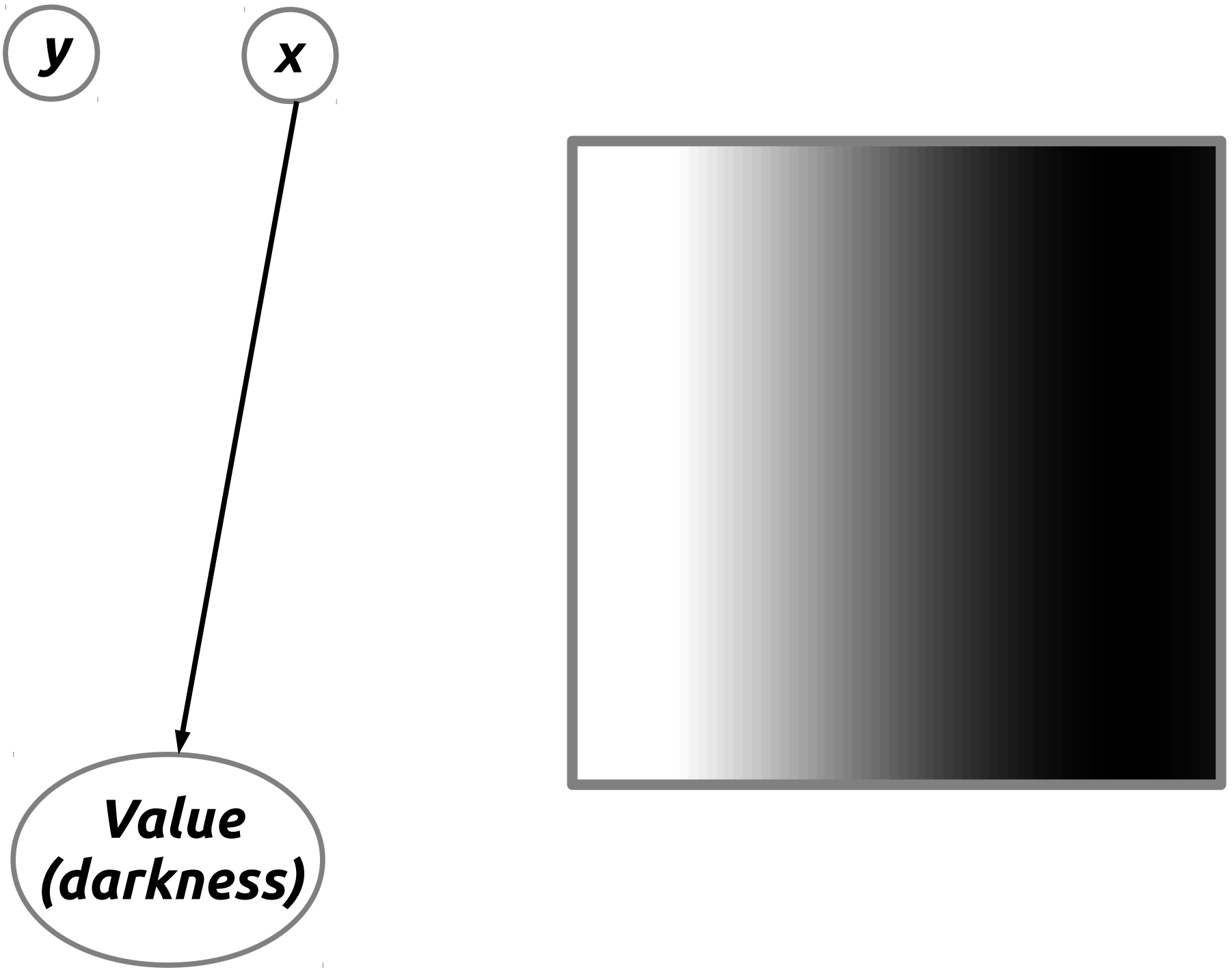
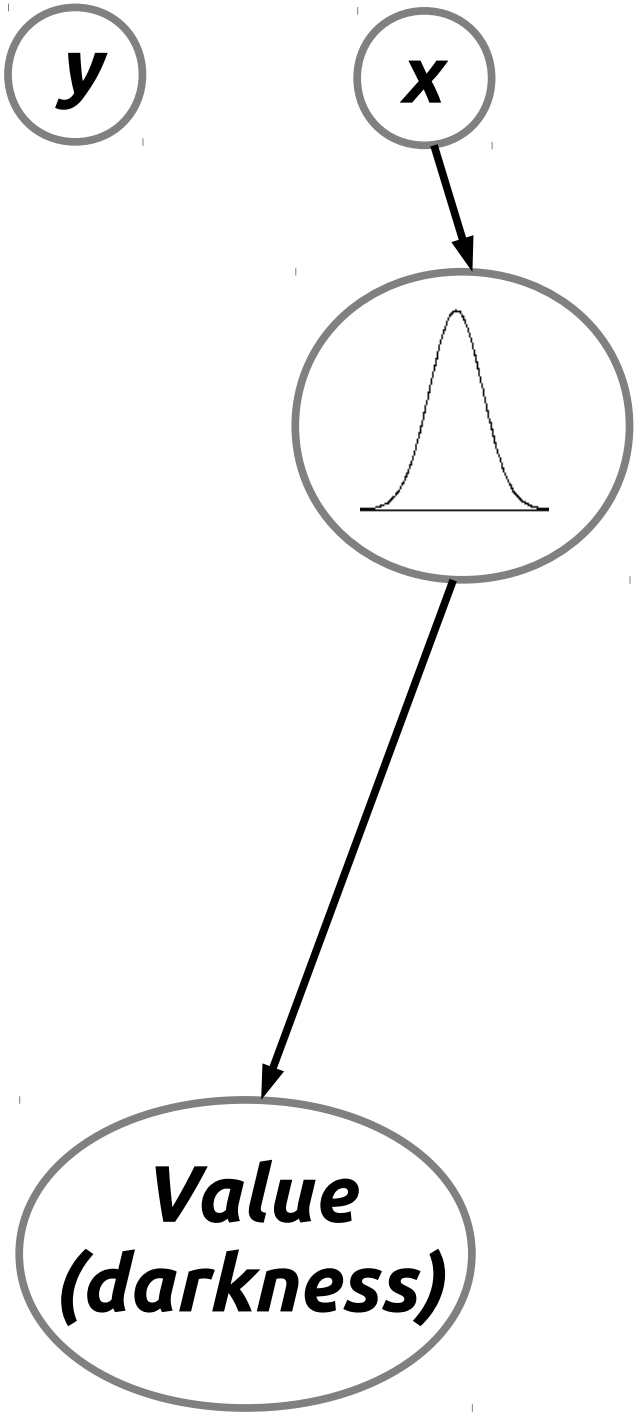
x
Value
(darkness)

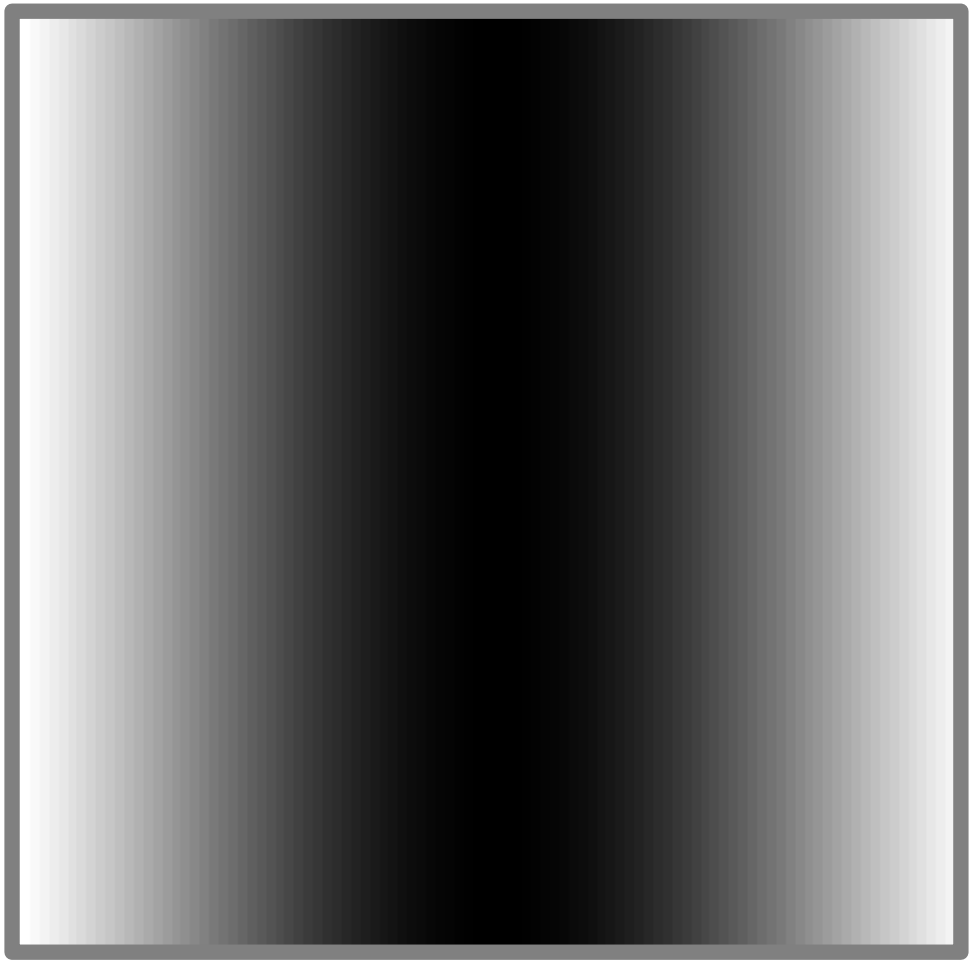

y
x
?
Value
(darkness)

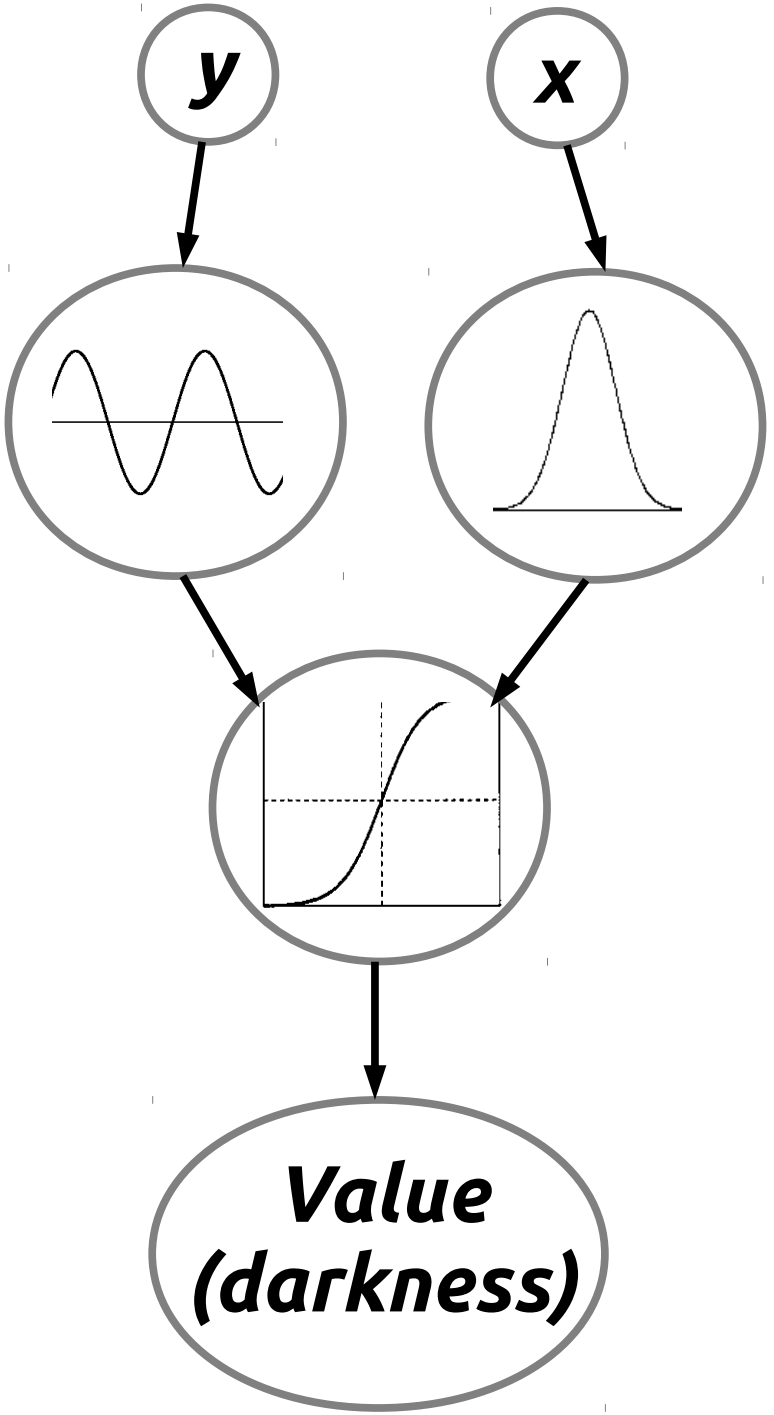

y
x
?
Value
(darkness)


y
x
?
Value
(darkness)


y
x
Value
(darkness)


y
x
Value
(darkness)




y
x
Value
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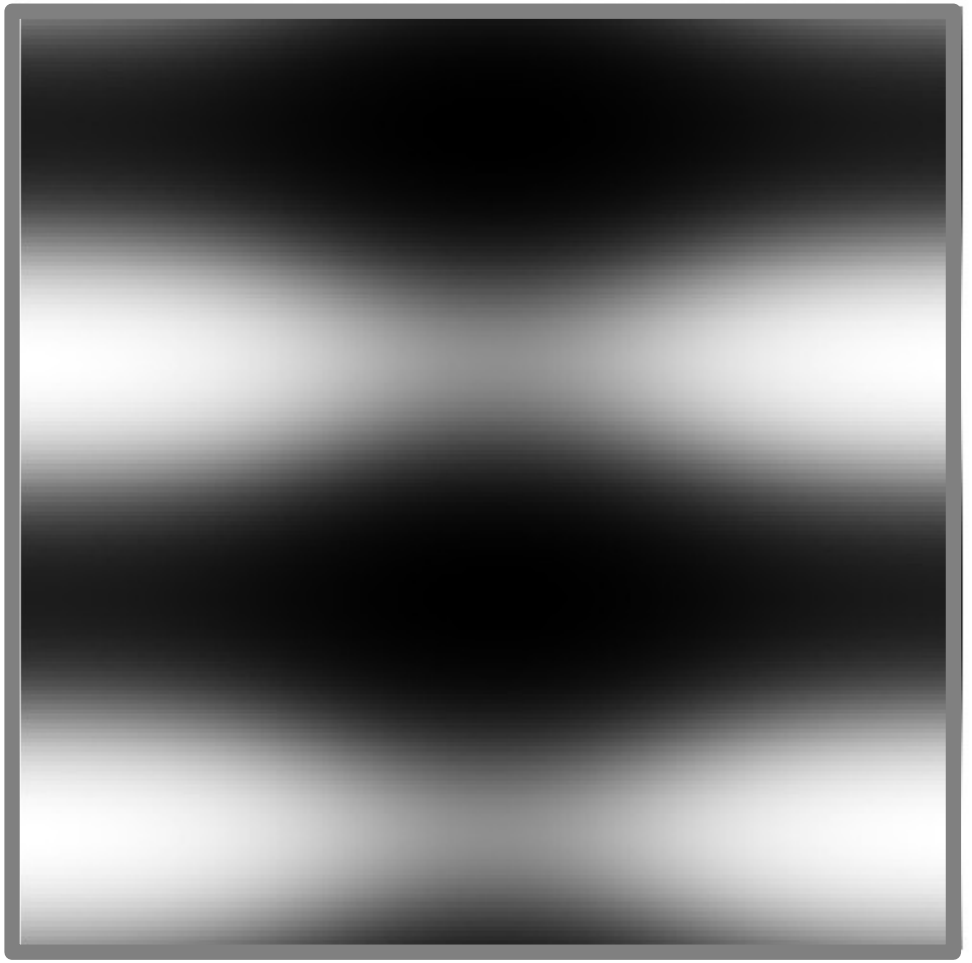
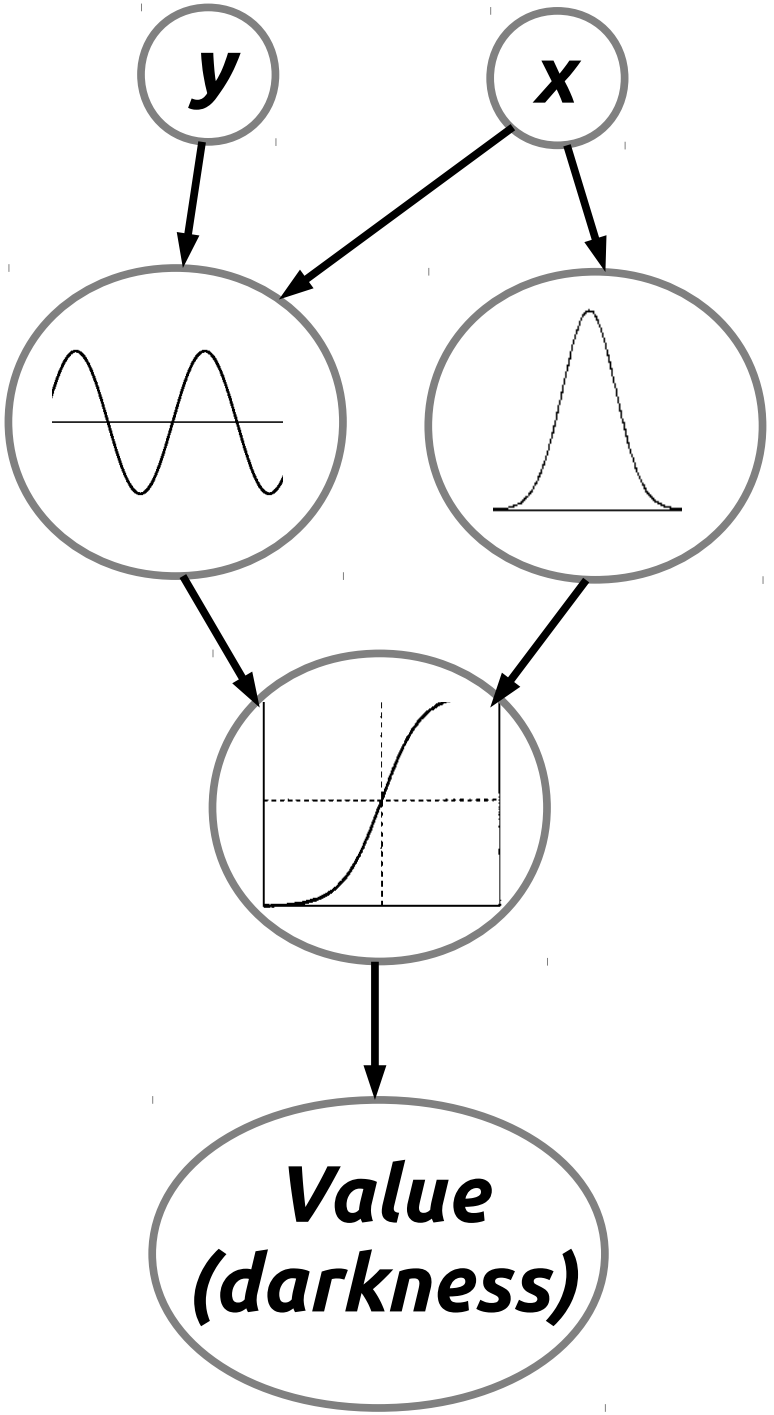
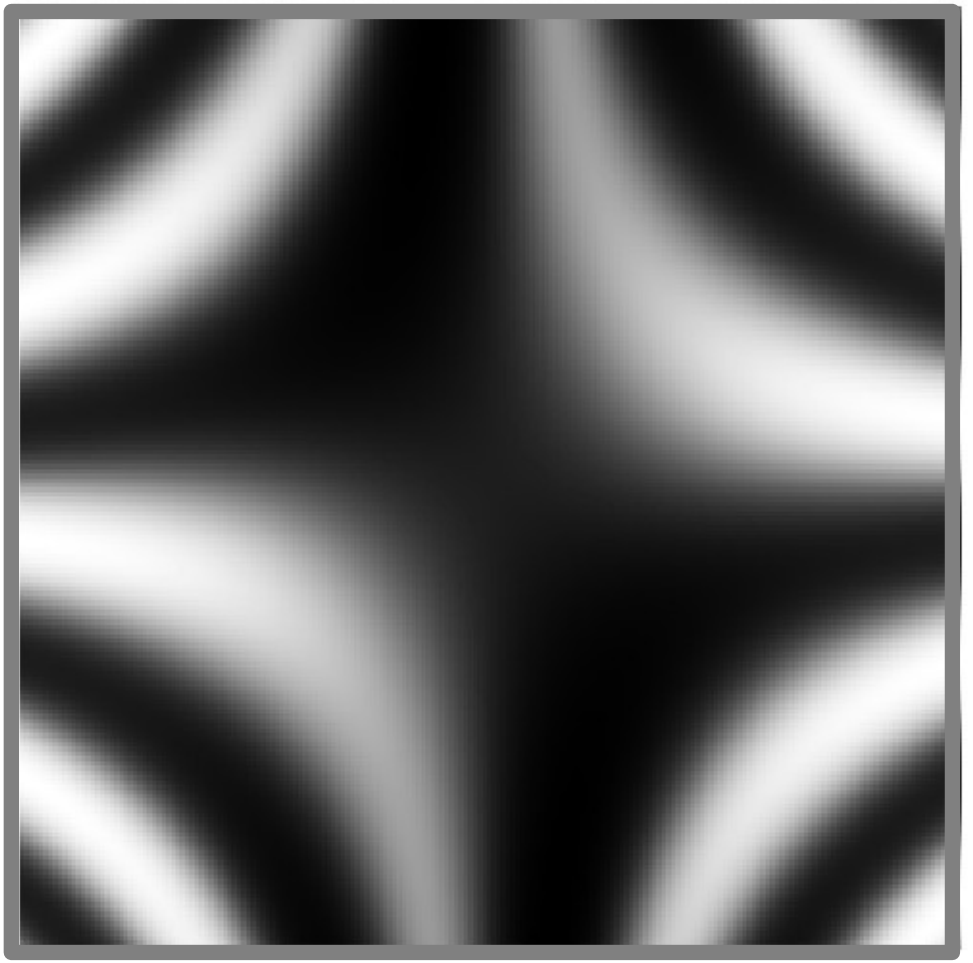
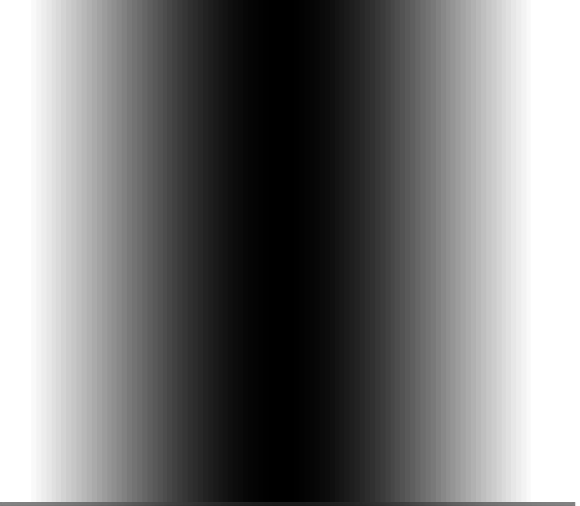
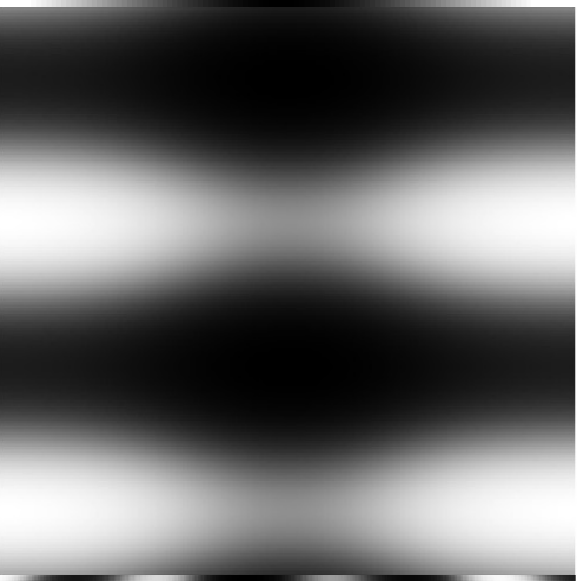
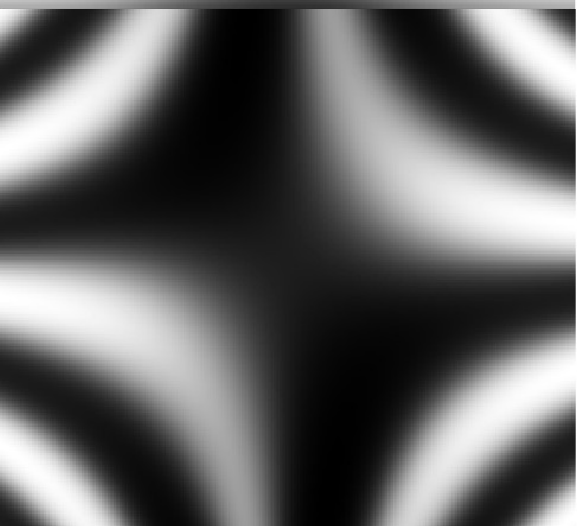


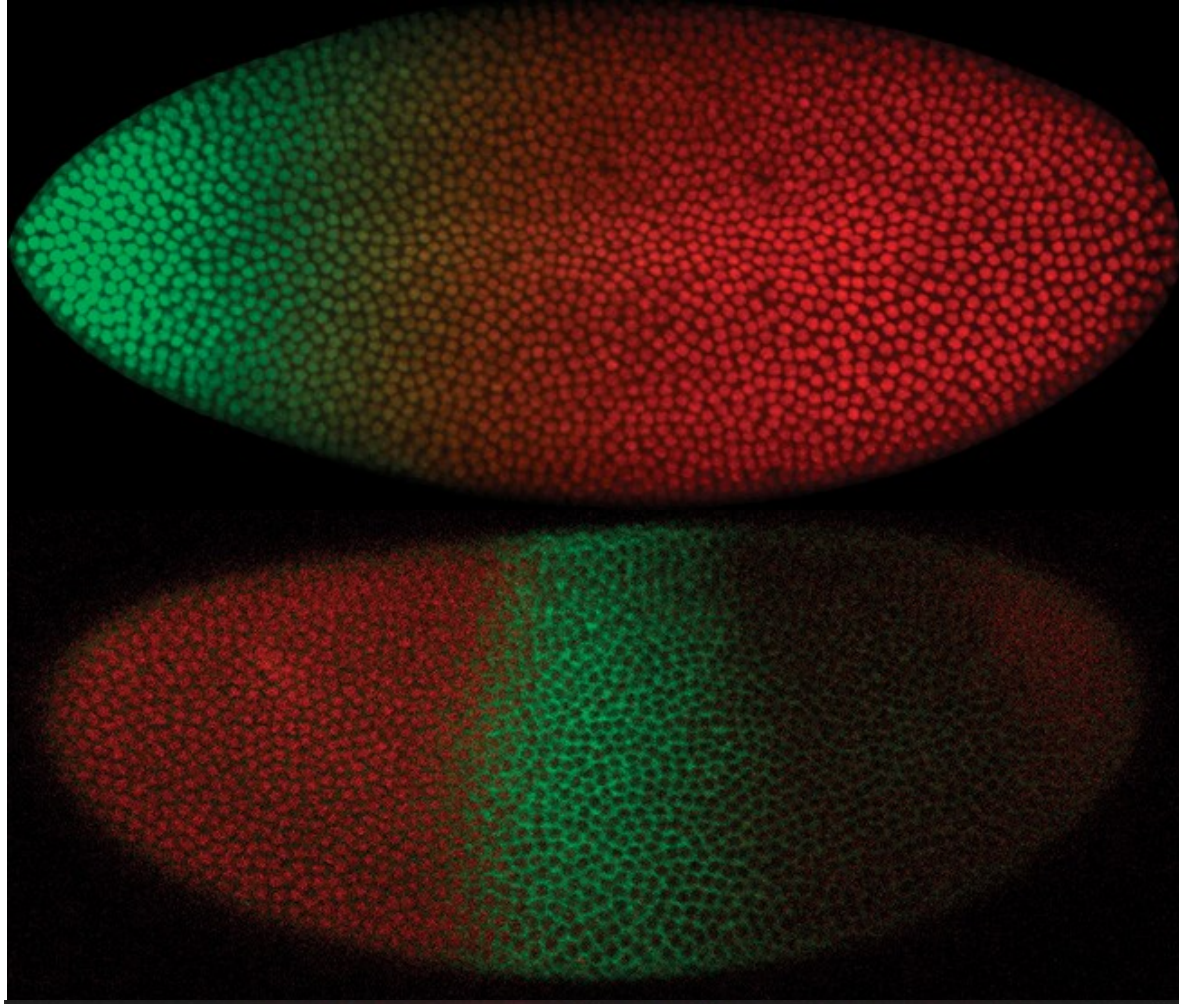

y
x
Value
(darkness)

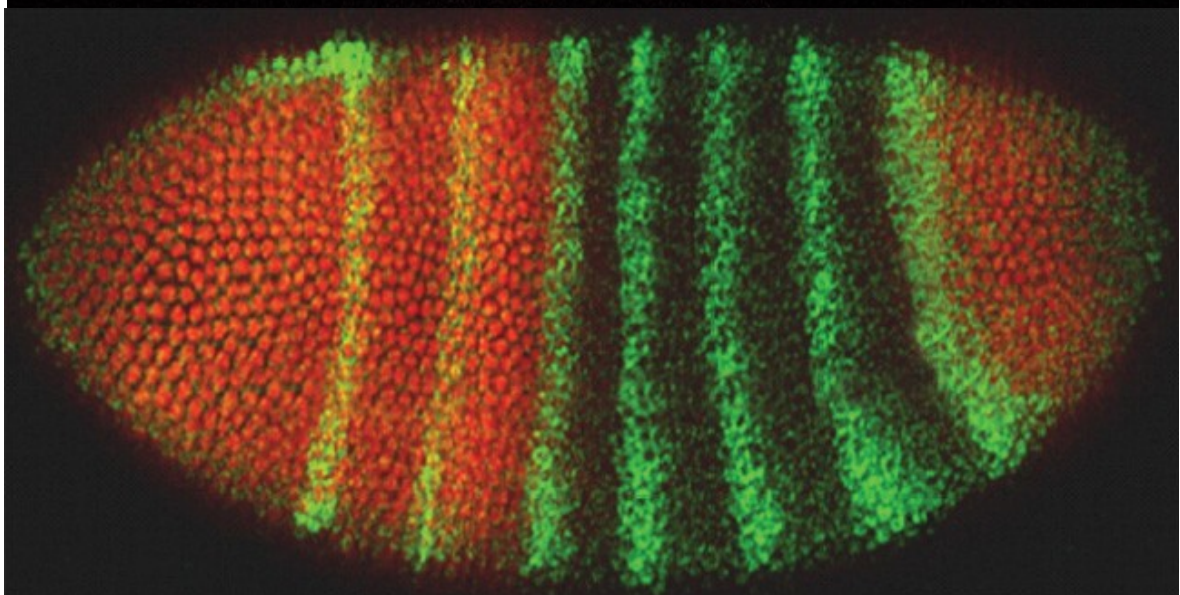


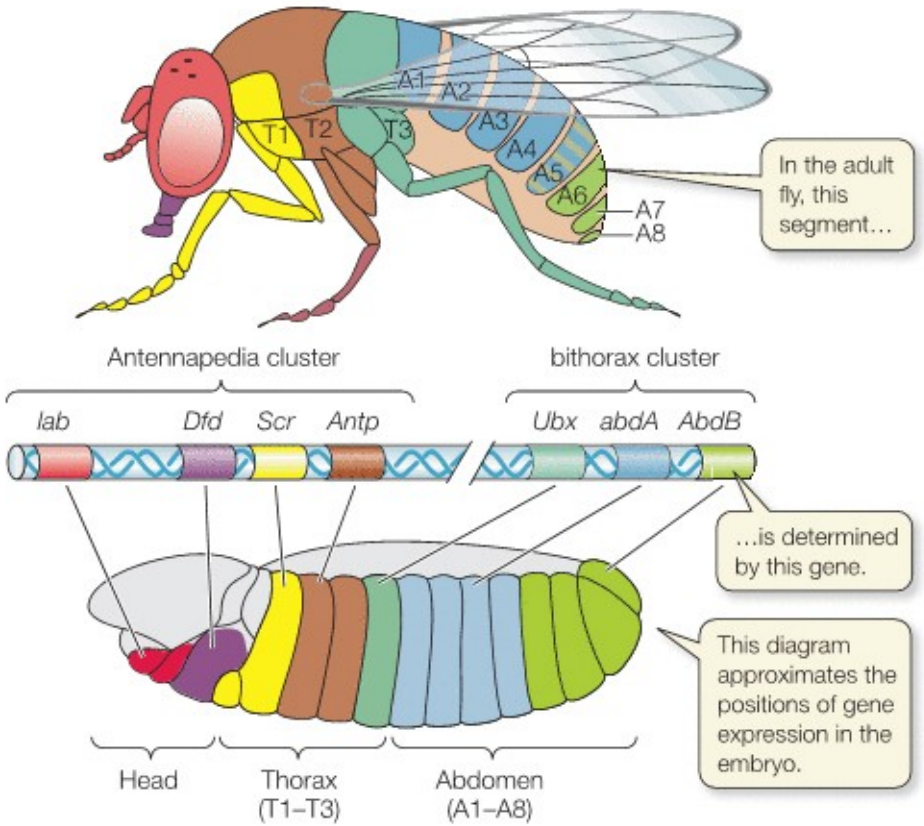


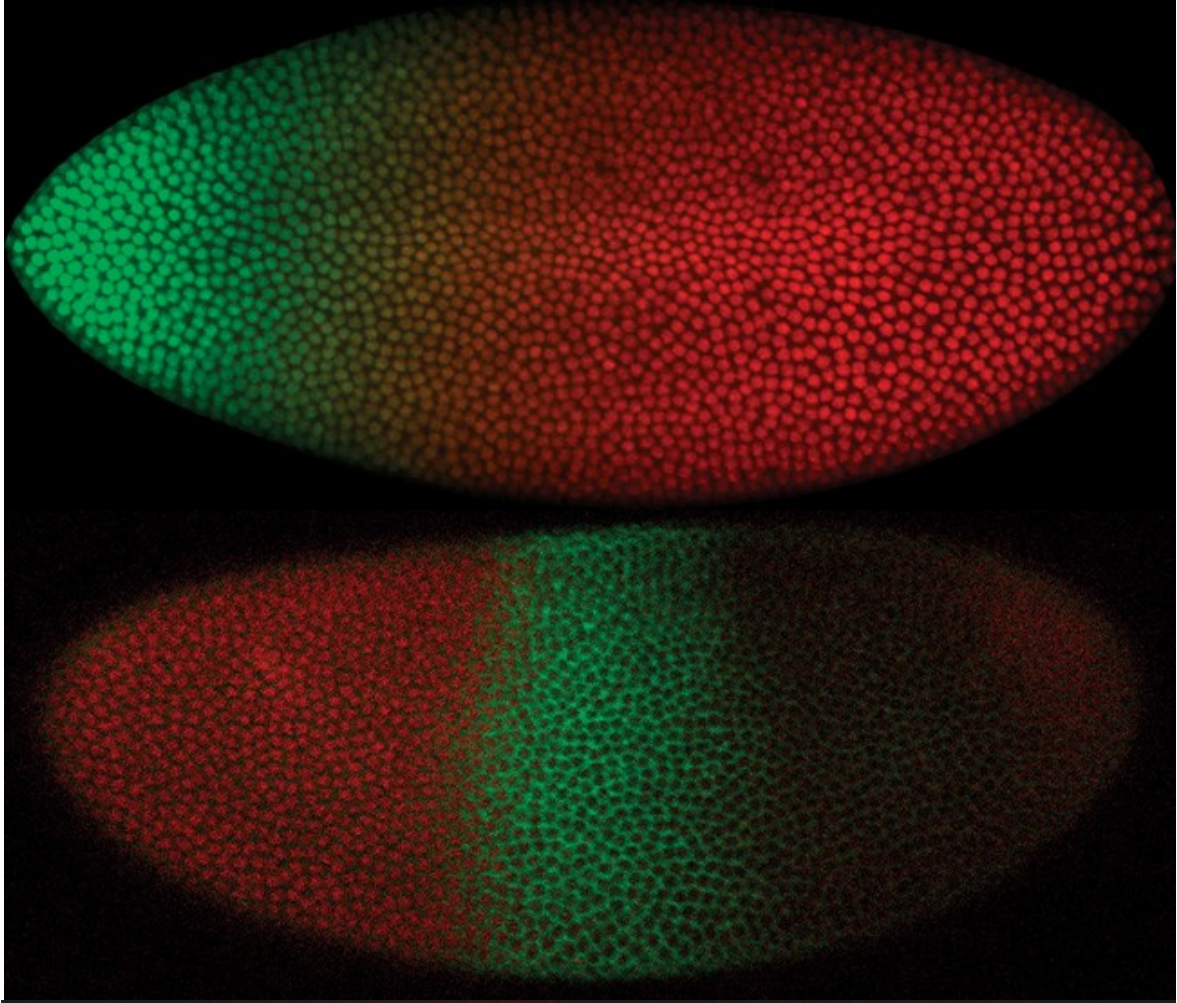


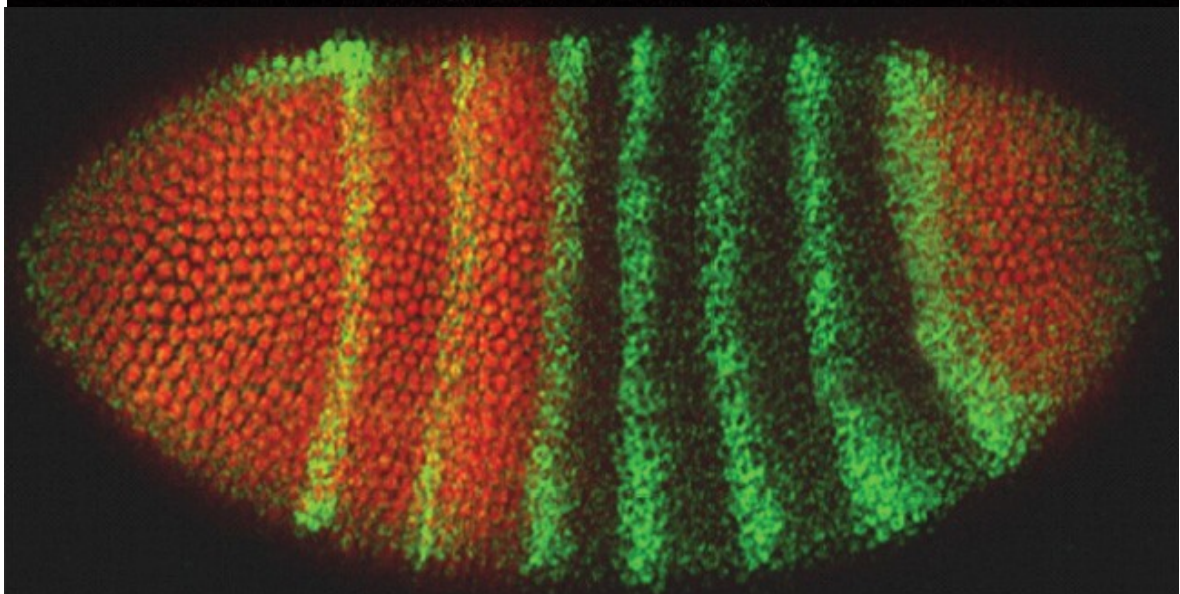







A1
A2
T1
T2
T3
A3
A4
A5
A6
A7
A8
In the adult fly, this segment…
Antennapedia cluster
bithorax cluster
lab
Dfd
Scr
Antp
Ubx
abdA
AbdB
…is determined by this gene.
This diagram approximates the positions of gene expression in the embryo.
Head
Thorax (T1–T3)
Abdomen (A1–A8)





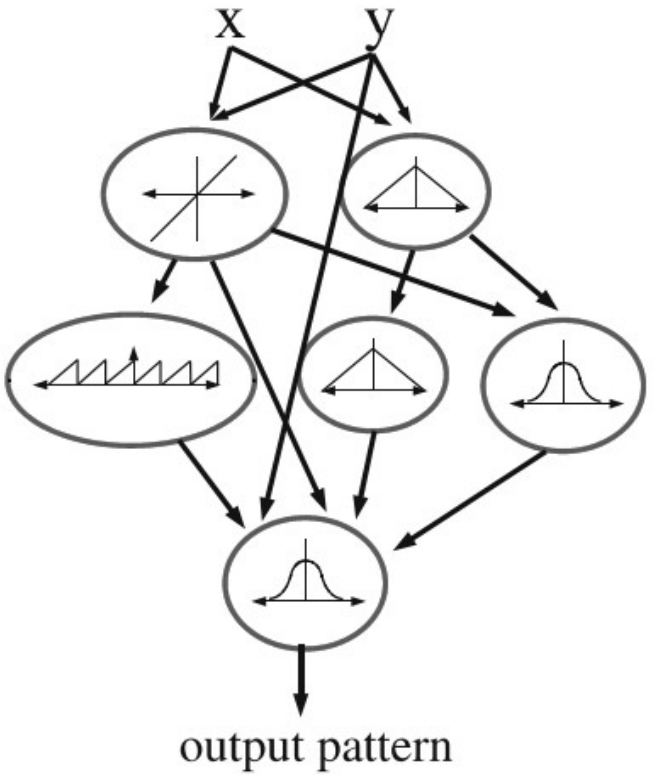


Fig. 4 *Composition of functions as a graph.* The graph determines which functions connect to which. The connections are weighted such that the output of a function is multiplied by the weight of its outgoing connection. If multiple connections feed into the same function, it means that the downstream function takes the sum of their weighted outputs. Note that the topology is unconstrained and can represent any possible relationships. This representation is similar to the formalism of artificial neural networks with arbitrary activation functions and topologies. Because the absolute coordinate frame (x,y) is input to the network, local interaction can be eliminated from the representation

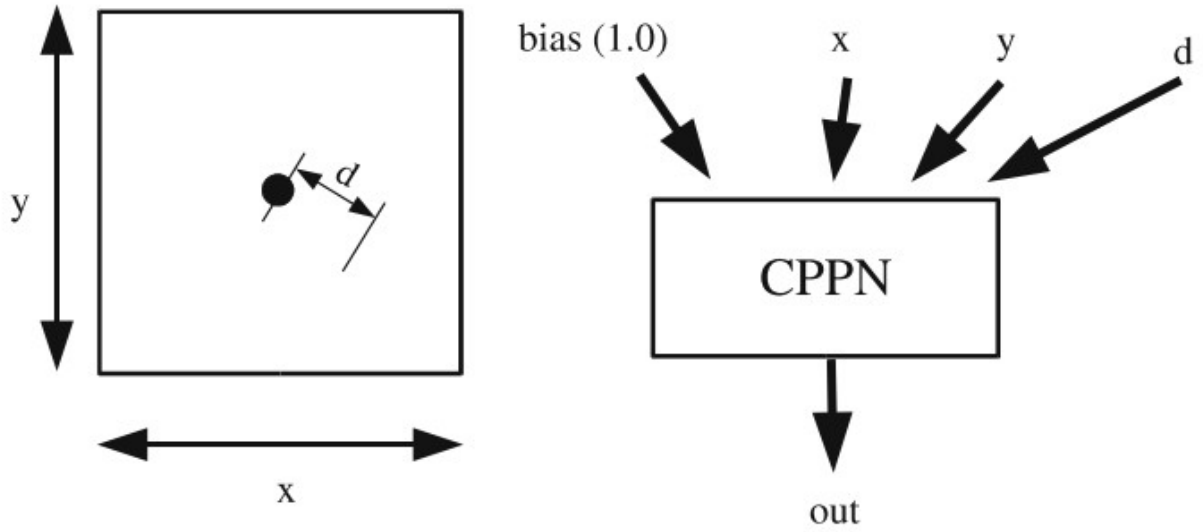


Fig. 6 *CPPN inputs*. Three values, the coordinate on the horizontal axis (x), the coordinate on the vertical axis (y), and the distance of the current coordinate from the center (d) are input into the CPPNs in the experiments in Sects. 4.2 and 4.3. Inputting d provides a bias towards symmetry. However, since d is radially symmetric, it does not automatically provide a bilaterally-symmetric coordinate frame

Pros:
Save computation by ignoring time/physics

Cons:
Keep gradients, patterning and complexification, but loose time-dependent aspects of development like heterochrony or canalization

picbreeder™

Inspired by how organisms evolve and complexify in nature

System Render

Controls

Basic Advanced Color

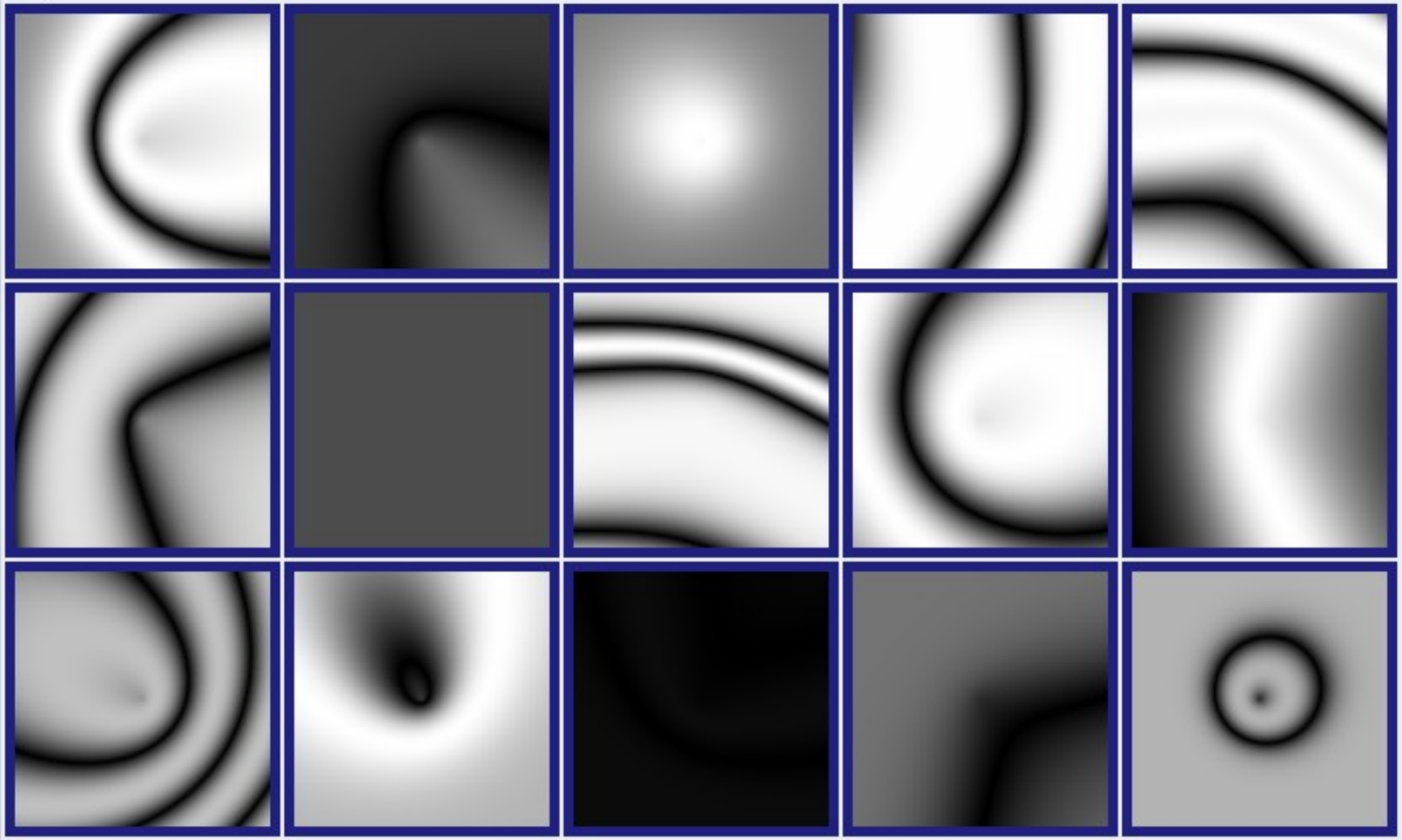
Quit Back Forward Redo Evolve Save Publish

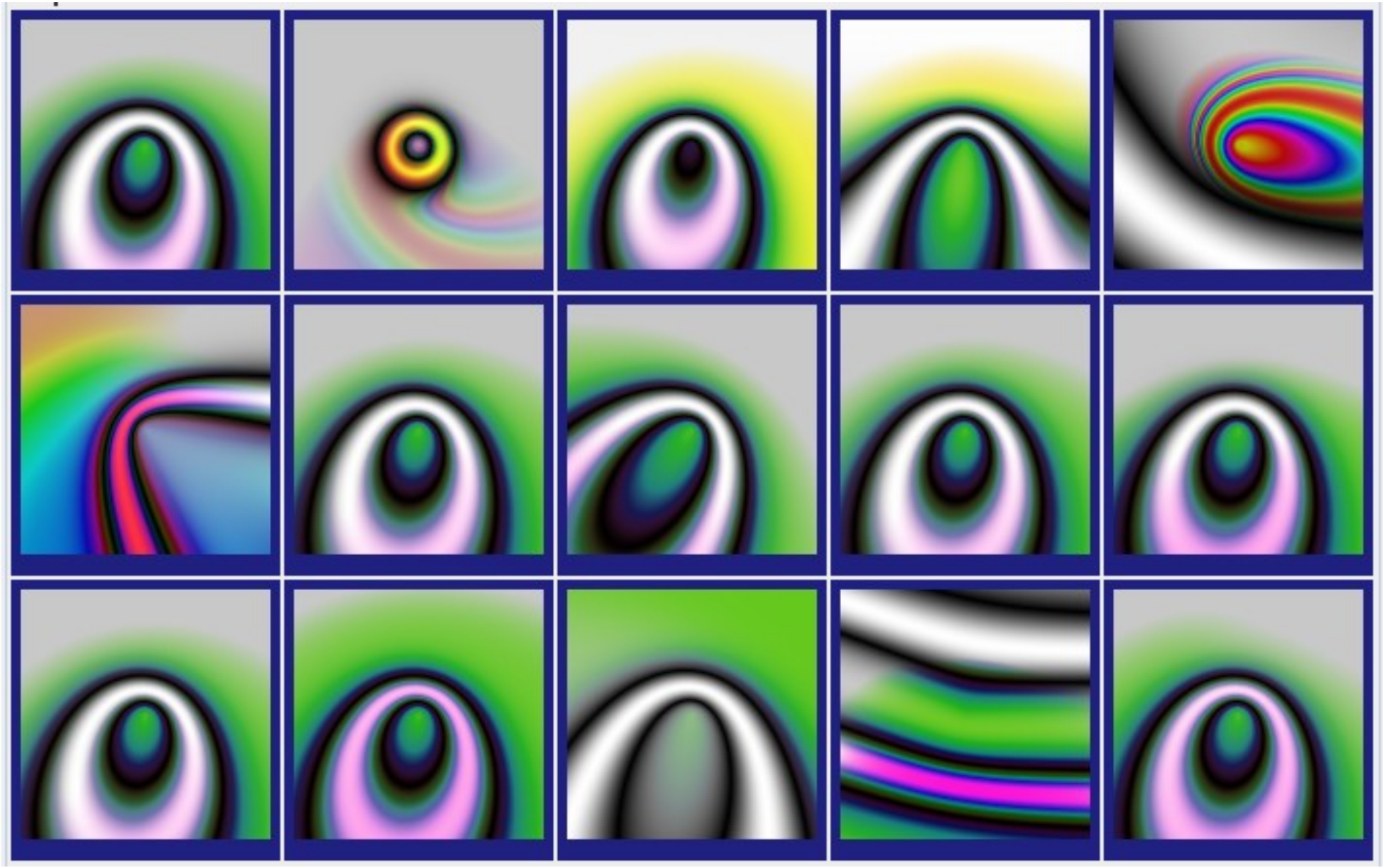
Guidance

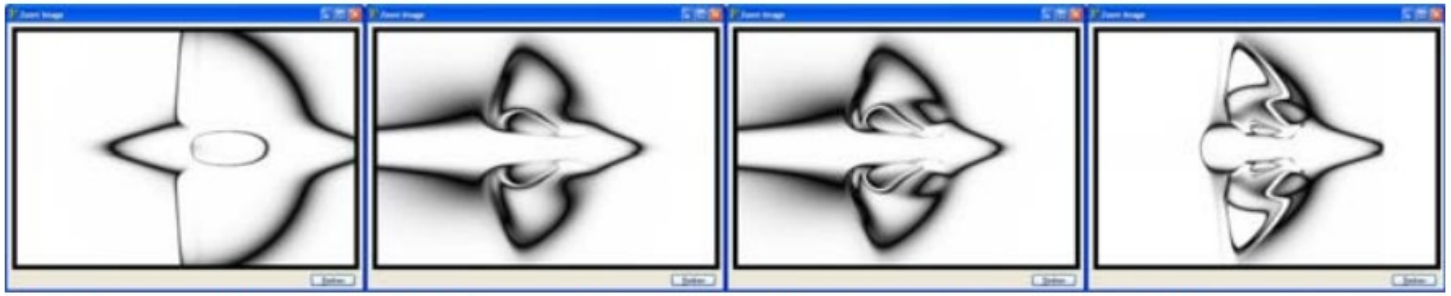
Focus: Both

Small Changes Big Changes

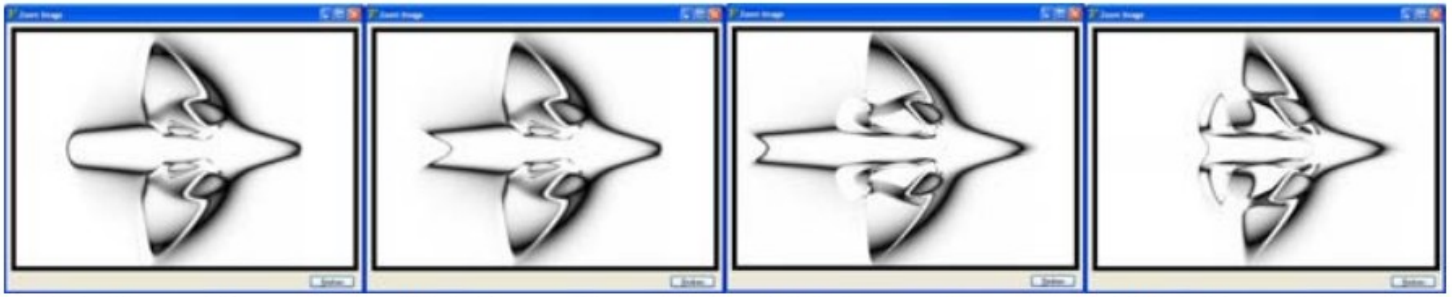
Population



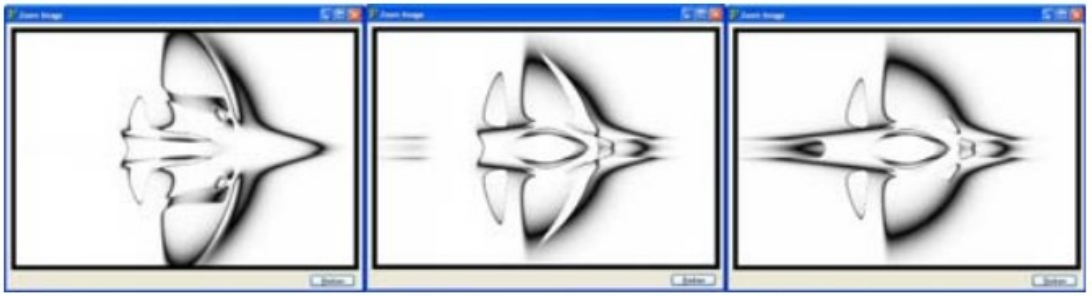




(a) 4 func., 17 conn. **(b)** 5 func., 24 conn. **(c)** 6 func., 25 conn. **(d)** 8 func., 28 conn.



(e) 8 func., 30 conn. **(f)** 8 func., 31 conn. **(g)** 8 func., 32 conn. **(h)** 8 func., 34 conn.



(i) 8 func., 36 conn. **(j)** 9 func., 36 conn. **(k)** 9 func., 38 conn.

Fig. 8 *Sequence of descendant spaceship patterns*. The chronological sequence (**a**)–(**k**) displays successive progeny evolved with interactive CPPN–NEAT. The number of hidden functions and connections in the generating CPPN is shown below each pattern. The sequence exhibits a continual elaboration of regular form in part analogous to natural elaboration

Live Demo!

(activation functions: sigmoid, sine, abs)

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"... from so simple a beginning ***endless forms*** most beautiful and most wonderful have been, and are being evolved."

— Charles Darwin, *On the Origin of Species*

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You can use the left and right arrow keys to rotate the objects.

Explore object designs by choosing those you like. Evolution produces objects in the next generation that are variants of those you choose, similar to how animals are bred and naturally evolve (more). Either further evolve an object below or start evolving from scratch.

Start Anew

Browse

best new
highest rated
newest
random
category
chess challenge

Best Users

current week
last week

Share It

Tweet

Follow Us

Evolve

angel with halo

Evolve

another carbonite face

Evolve

lamp

Evolve

coke bottle

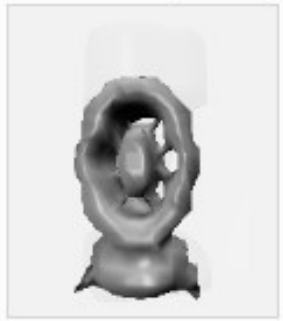
Evolve

face

Evolve

queen

Evolve

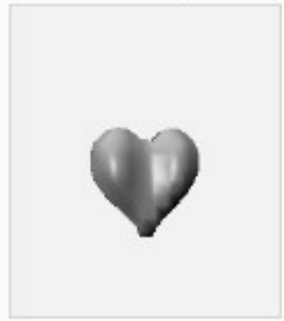


Mounted Turbine

Evolve

Space Drive

Evolve



heart

Evolve

multiple demonsional

« Prev

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Next »

[Clune et al. 2011]

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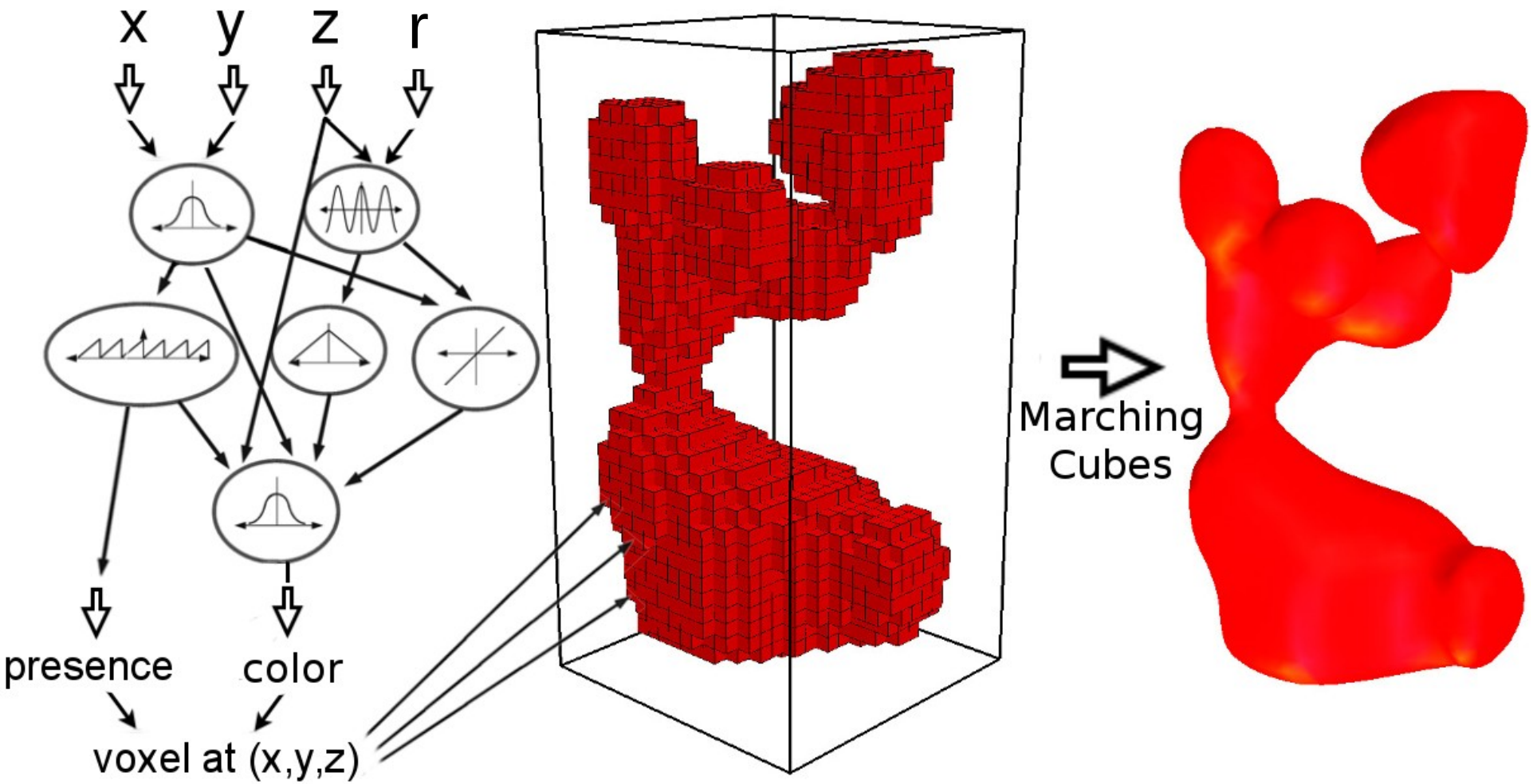
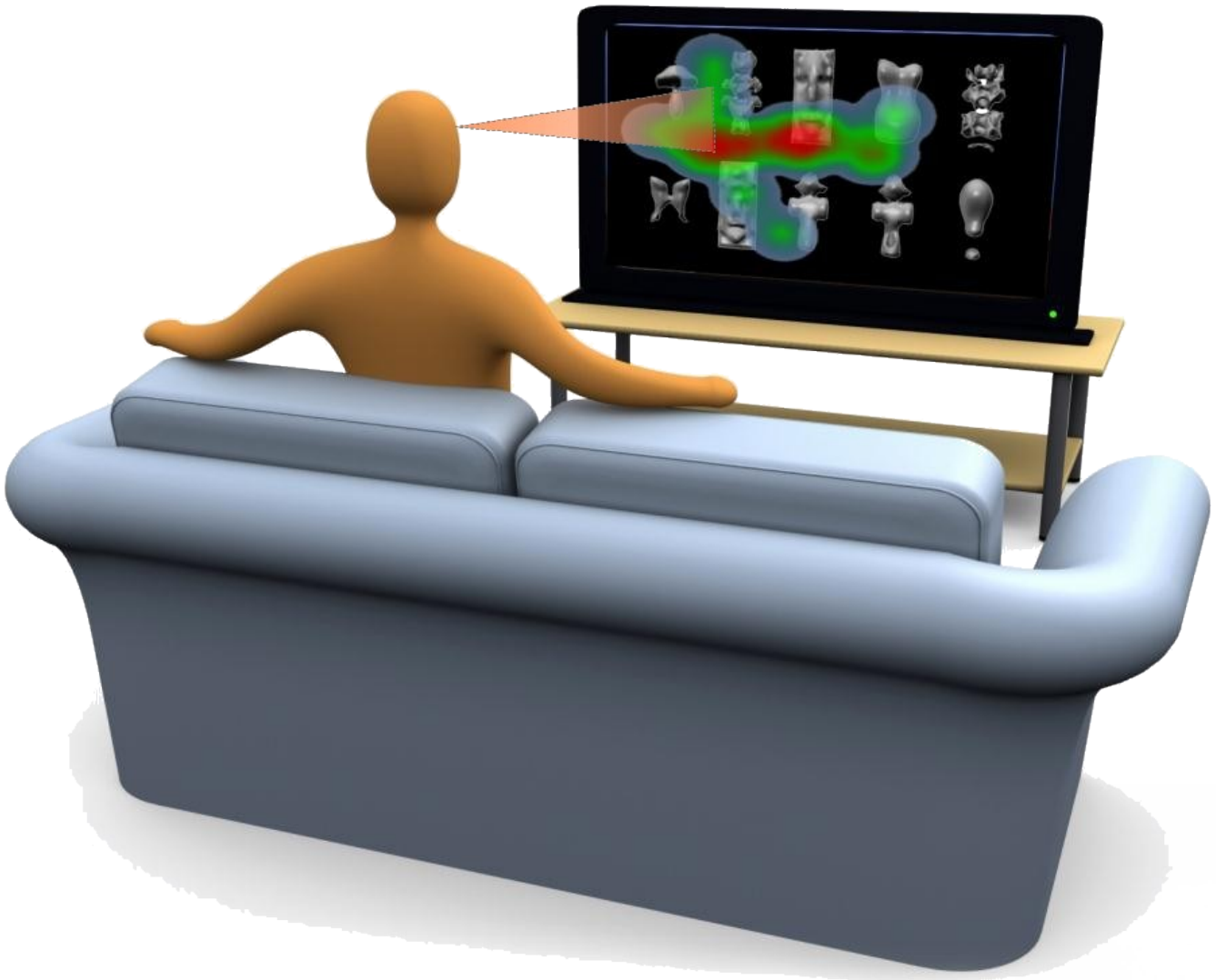
Cornell Creative Machines Lab


x
y
z
r
presence
color
voxel at (x,y,z)
Marching
Cubes




tobii
Glasses Head Unit
tobii