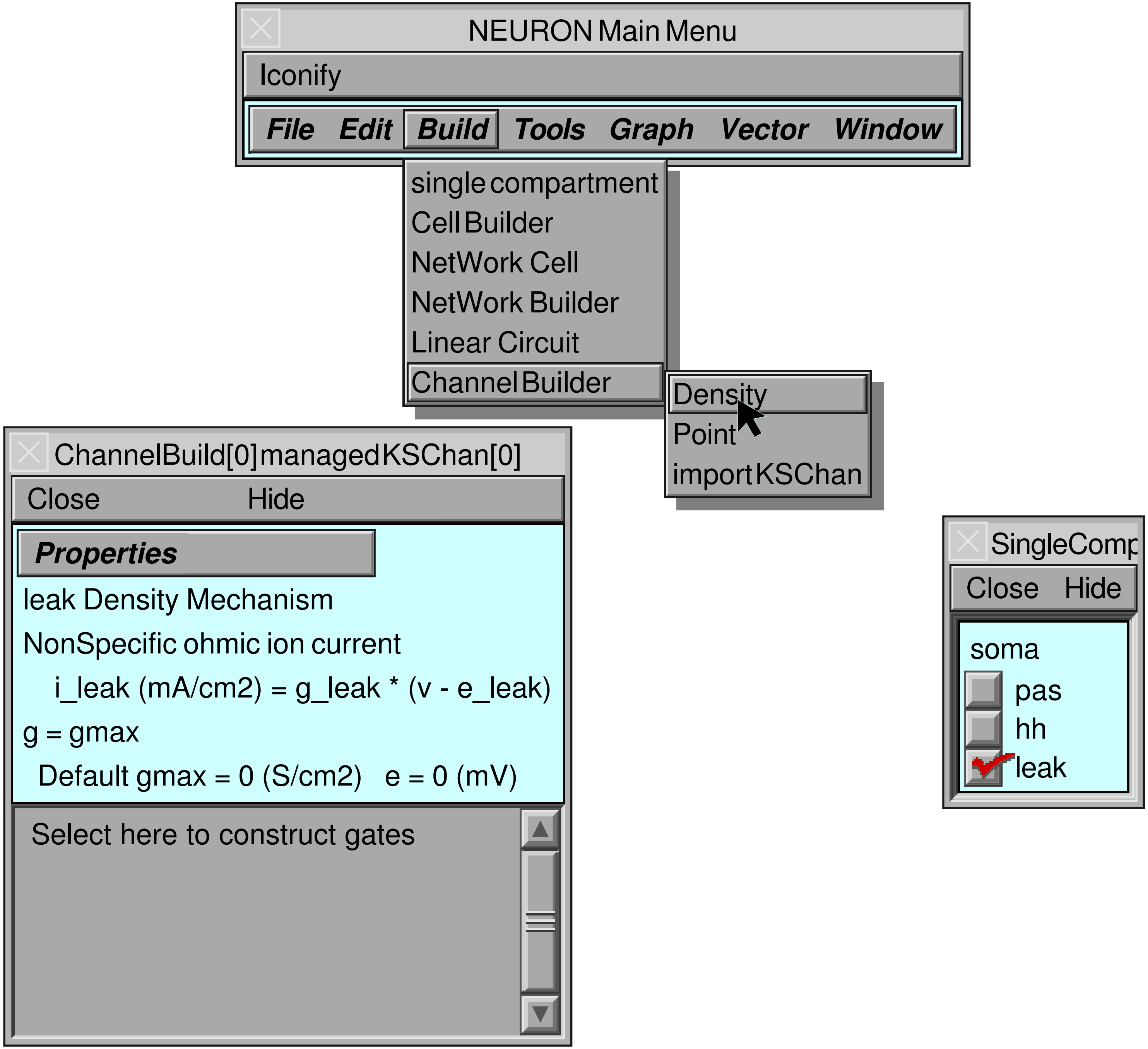
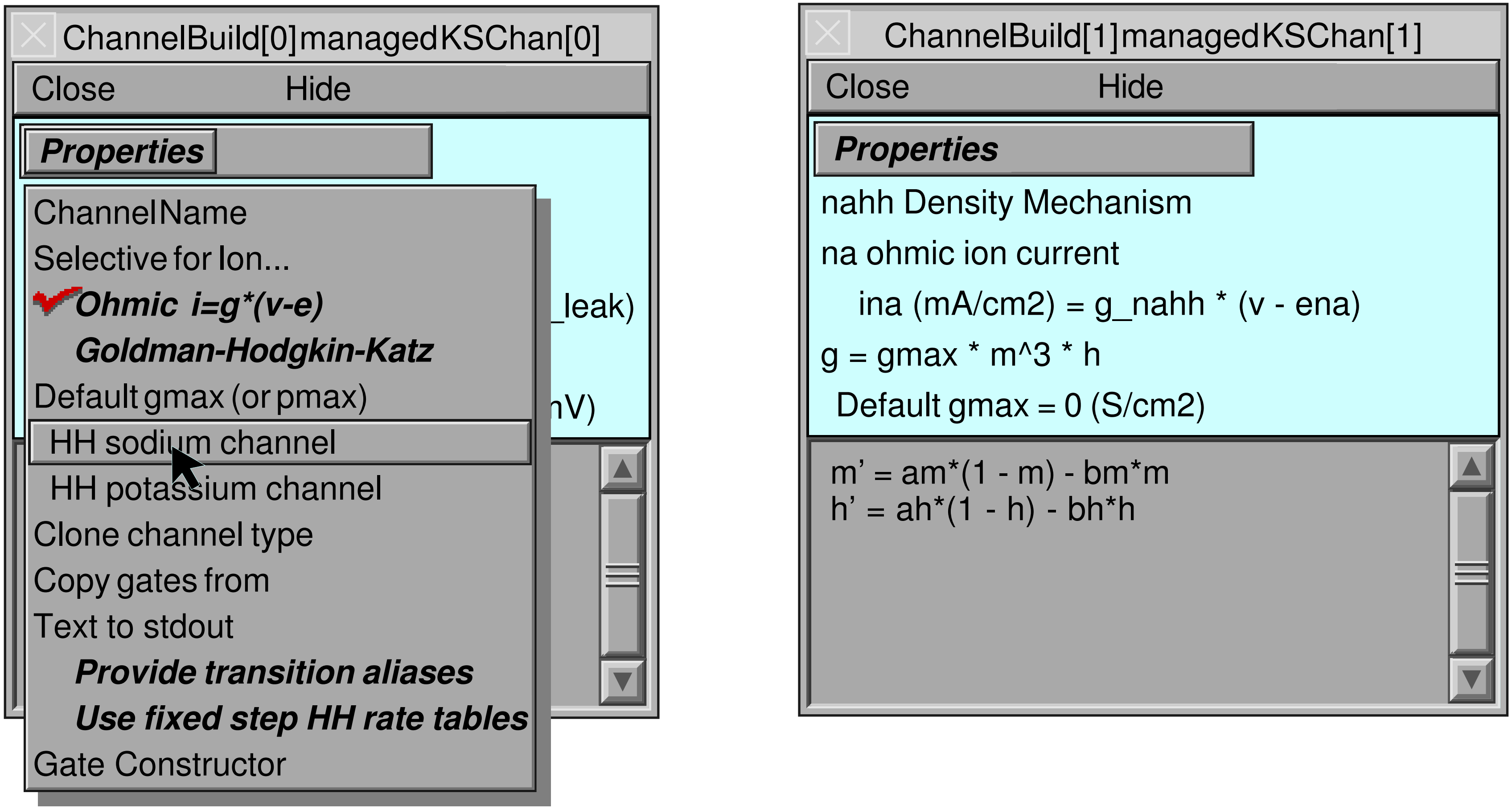
Recent Developments in NEURON

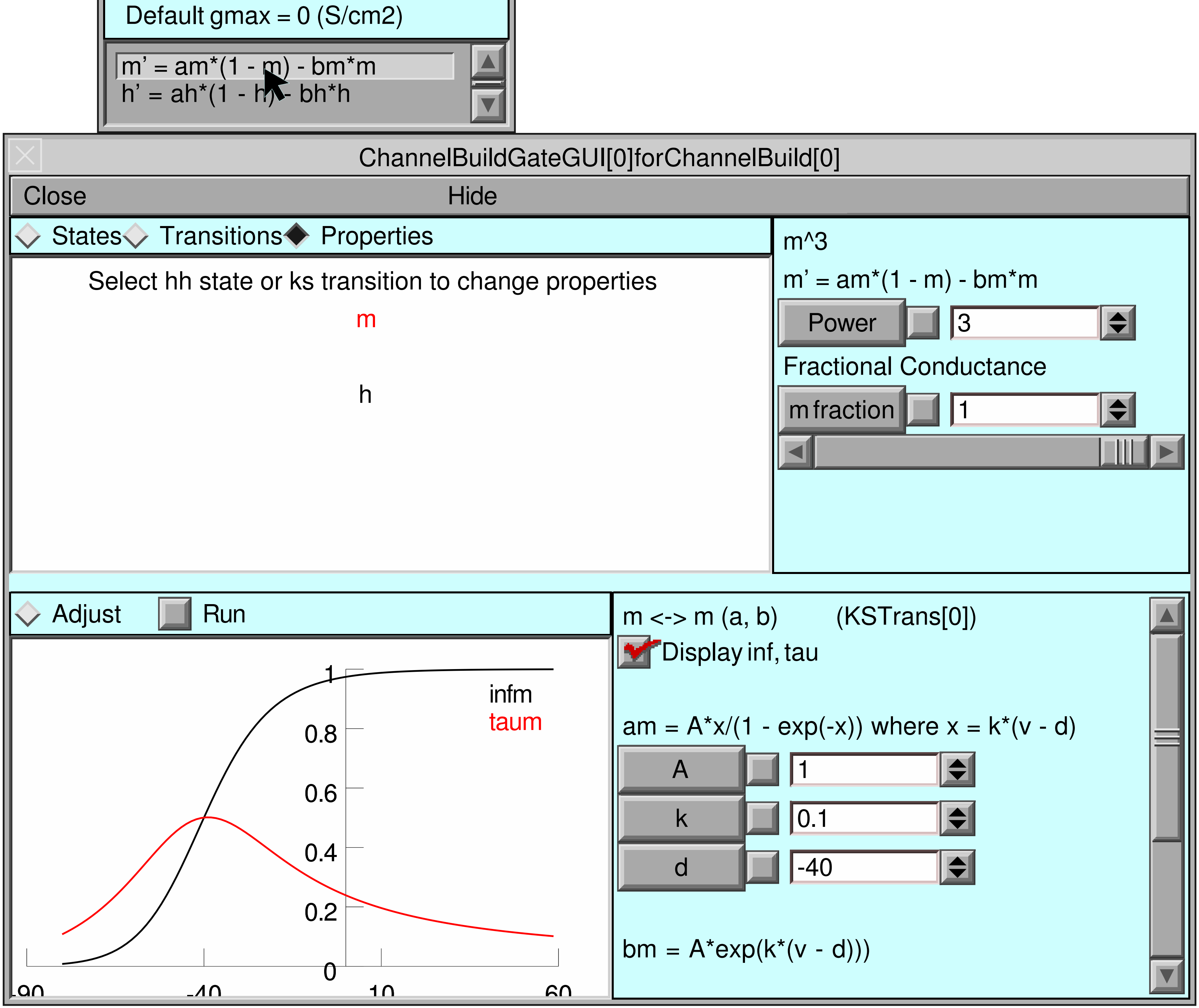
Channel Builder
Import 3–D reconstructions
Cell Builder: Inhomogeneous Parameters
Model View

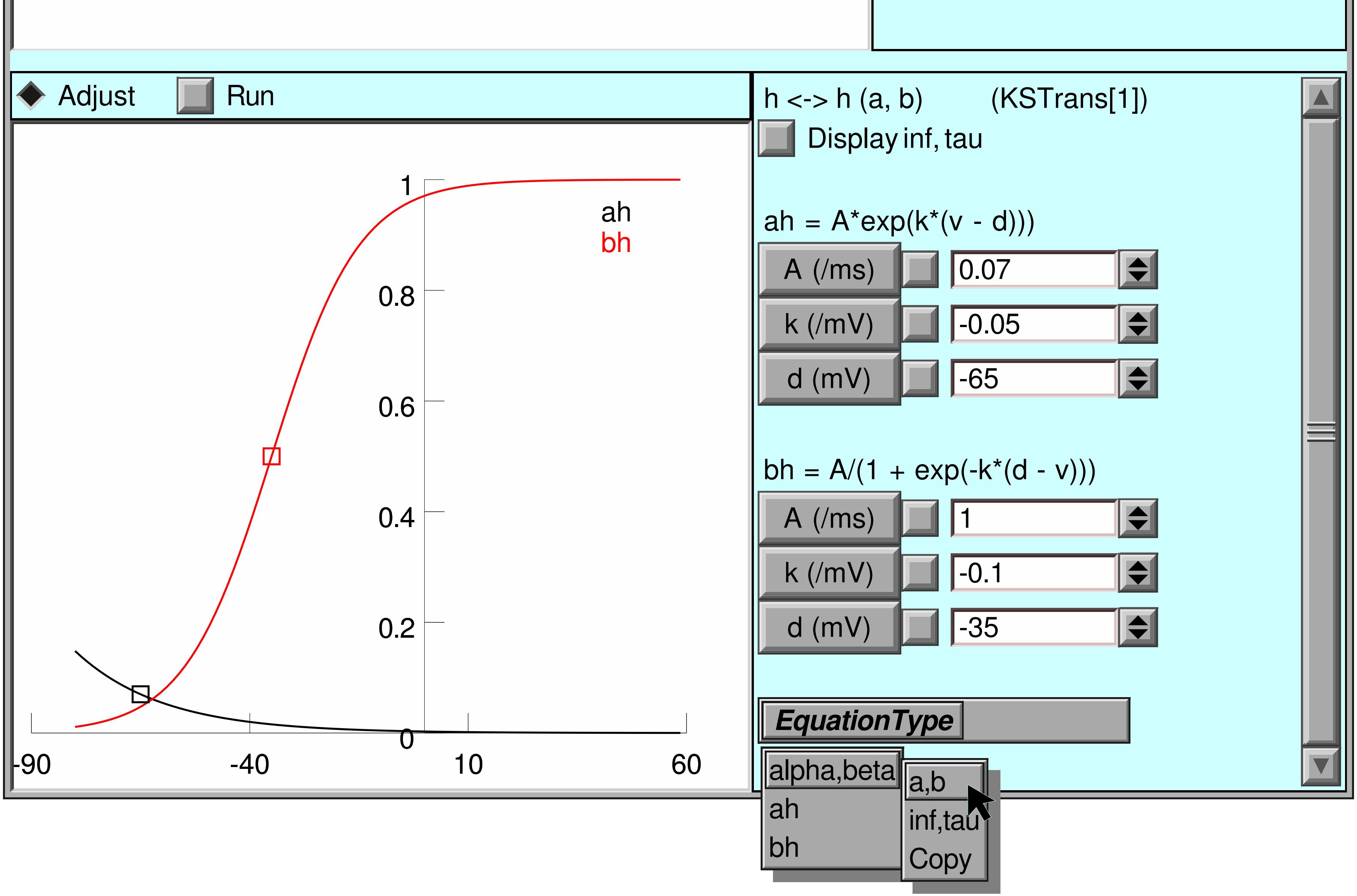
DAE Variable Step Method
State Transition Events
Local Variable Time–Step Method:
Second order condition evaluation
Artificial Spiking Cells:
Discrete Event Simulations


NEURON Main Menu
Iconify
File Edit Build Tools Graph Vector Window
single compartment
Cell Builder
NetWork Cell
NetWork Builder
Linear Circuit
Channel Builder
Density
Point
import KSChan
ChannelBuild[0]managedKSChan[0]
Close Hide
Properties
leak Density Mechanism
NonSpecific ohmic ion current
i_leak (mA/cm2) = g_leak * (v - e_leak)
g = gmax
Default gmax = 0 (S/cm2) e = 0 (mV)
Select here to construct gates
SingleComp
Close Hide
soma
pas
hh
leak

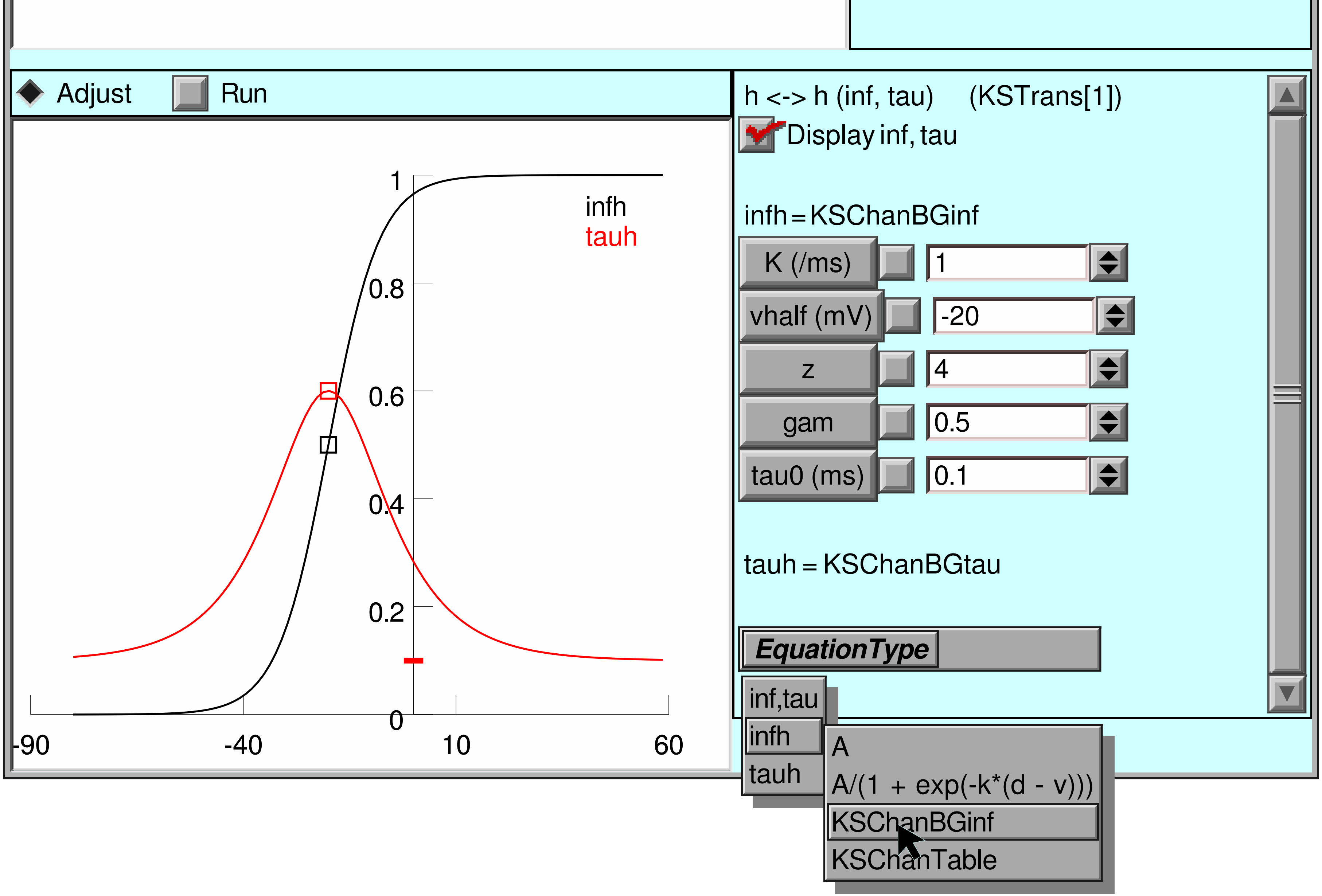


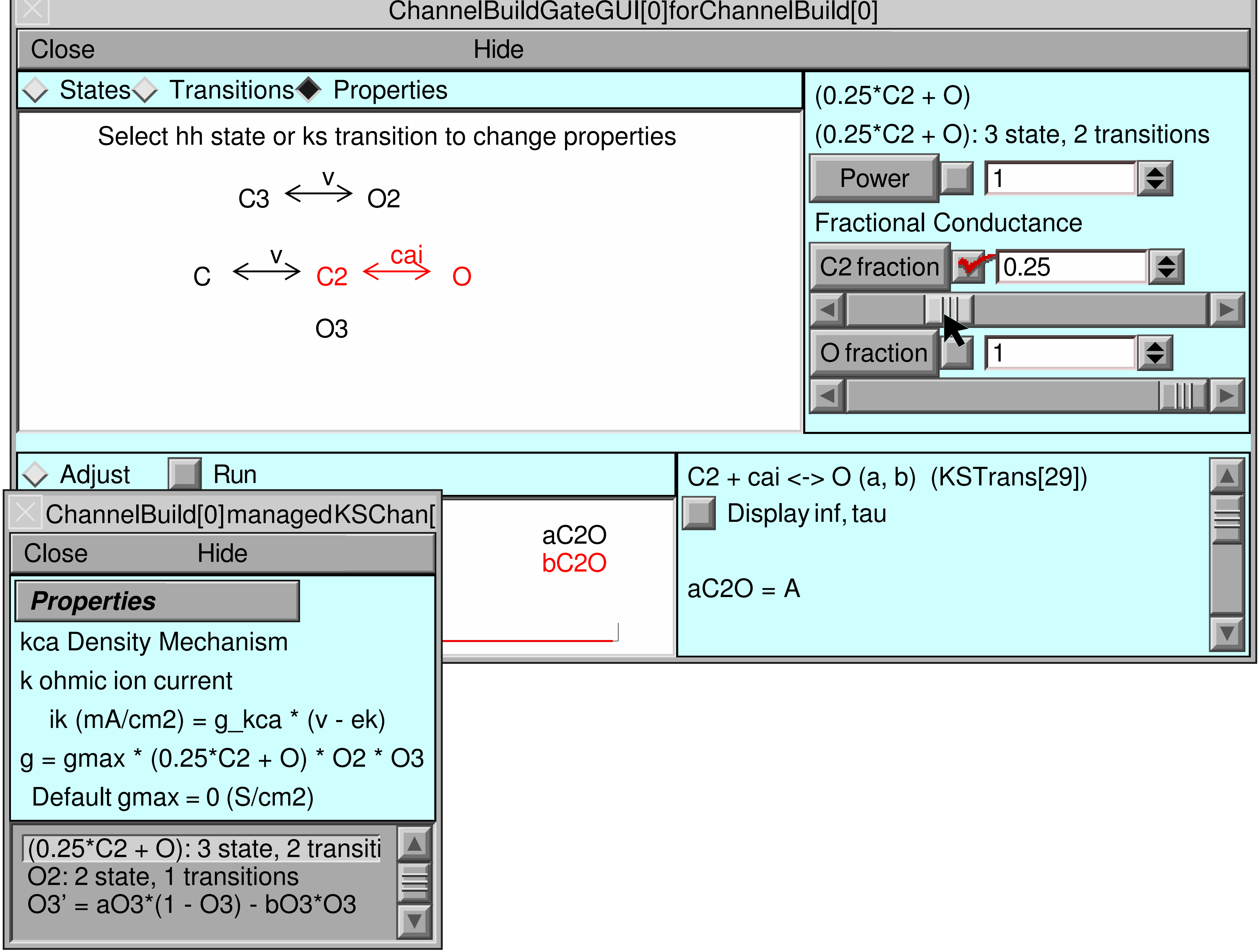
ChannelBuild[0]managedKSChan[0]
Close
Hide
Properties
ChannelName
Selective for Ion...
Ohmic i=g*(v-e)
Goldman-Hodgkin-Katz
Default gmax (or pmax)
HH sodium channel
HH potassium channel
Clone channel type
Copy gates from
Text to stdout
Provide transition aliases
Use fixed step HH rate tables
Gate Constructor
ChannelBuild[1]managedKSChan[1]
Close
Hide
Properties
nahh Density Mechanism
na ohmic ion current
ina (mA/cm2) = g_nahh * (v - ena)
g = gmax * m^3 * h
Default gmax = 0 (S/cm2)
m' = am*(1 - m) - bm*m
h' = ah*(1 - h) - bh*h


Default gmax = 0 (S/cm2)
m' = am*(1 - m) - bm*m
h' = ah*(1 - h) - bh*h
ChannelBuildGateGUI[0]forChannelBuild[0]
Close
Hide
States
Transitions
Properties
Select hh state or ks transition to change properties
m
h
m^3
m' = am*(1 - m) - bm*m
Power
3
Fractional Conductance
m fraction
1
Adjust
Run
1
0.8
0.6
0.4
0.2
0
-90
-40
10
60
infm
taum
m <-> m (a, b)
(KSTrans[0])
Display inf, tau
am = A*x/(1 - exp(-x)) where x = k*(v - d)
A
1
k
0.1
d
-40
bm = A*exp(k*(v - d)))

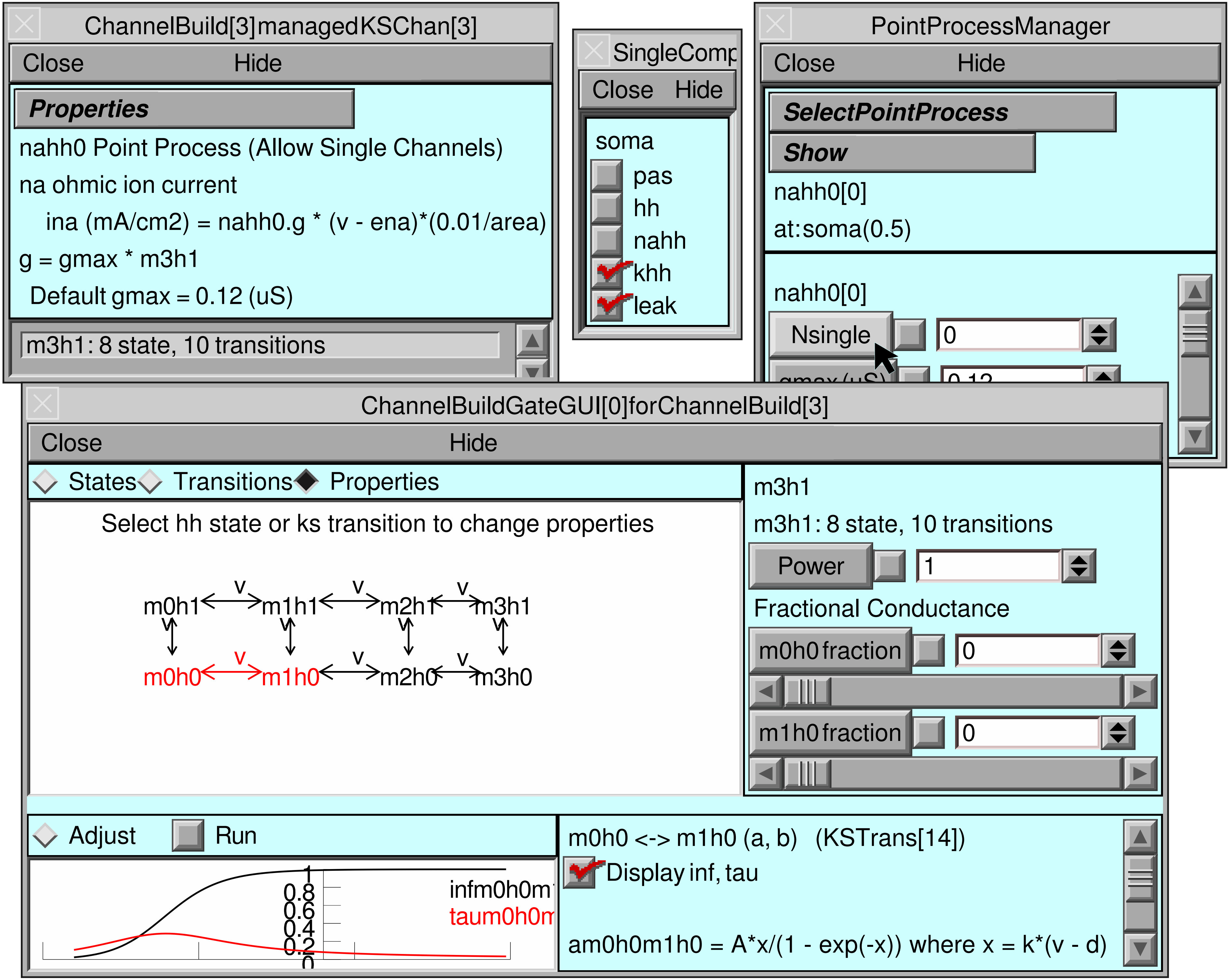


Adjust
Run
h <-> h (a, b)
(KSTrans[1])
Display inf, tau
ah = A*exp(k*(v - d)))
A (/ms)
0.07
k (/mV)
-0.05
d (mV)
-65
bh = A/(1 + exp(-k*(d - v)))
A (/ms)
1
k (/mV)
-0.1
d (mV)
-35
EquationType
alpha,beta
ah
bh
a,b
inf,tau
Copy
ah
bh
1
0.8
0.6
0.4
0.2
0
-90
-40
10
60

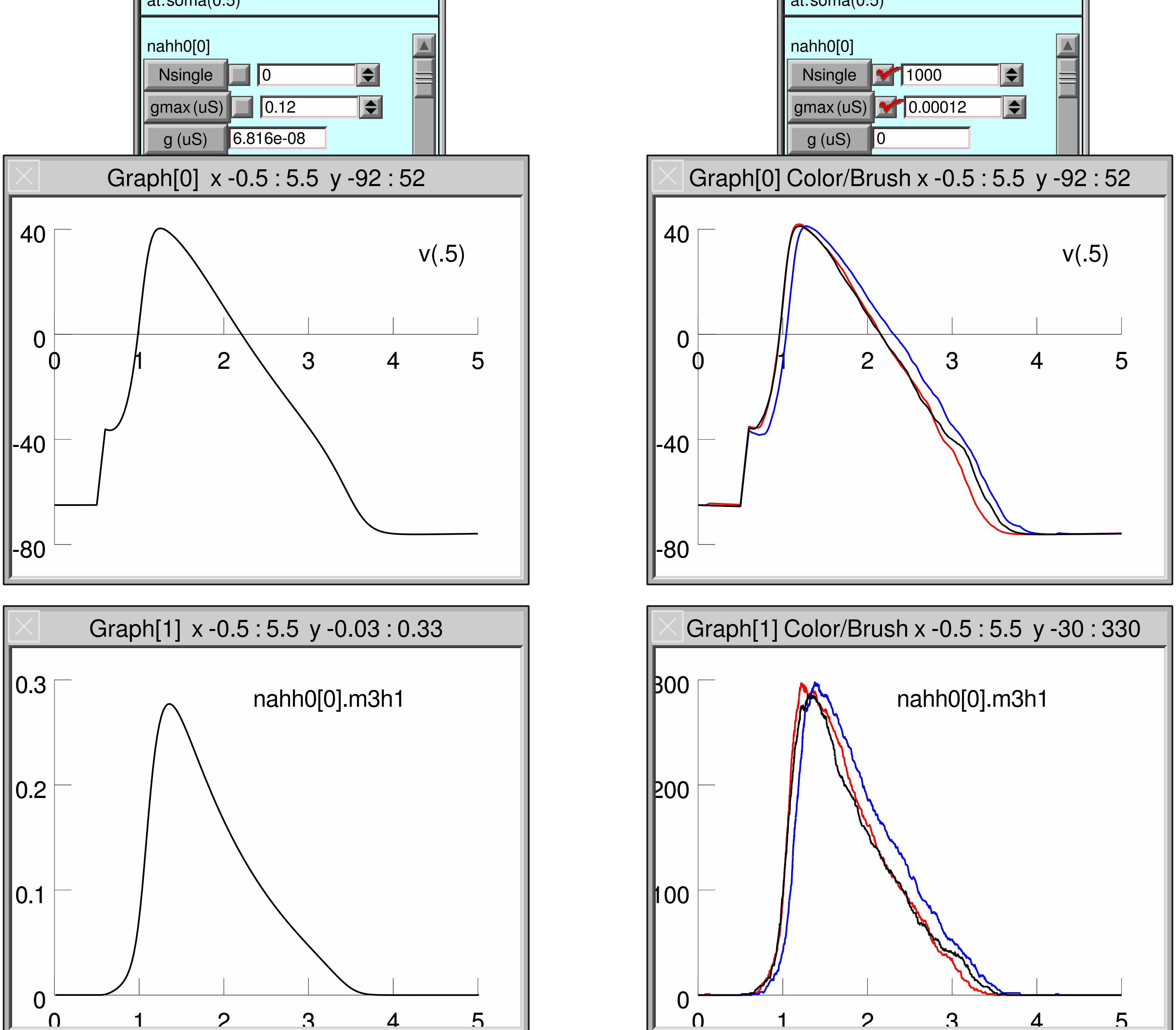

Adjust
Run
1
0.8
0.6
0.4
0.2
0
-90
-40
10
60
infh
tauh
h <-> h (inf, tau)   (KSTrans[1])
Display inf, tau
infh = KSChanBGinf
K (/ms)
1
vhalf (mV)
-20
z
4
gam
0.5
tau0 (ms)
0.1
tauh = KSChanBGtau
EquationType
inf,tau
infh
tauh
A
A/(1 + exp(-k*(d - v)))
KSChanBGinf
KSChanTable

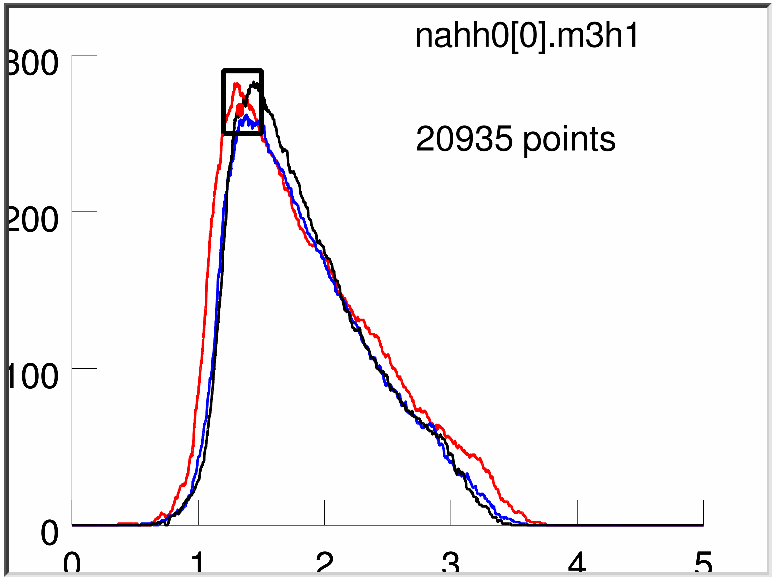


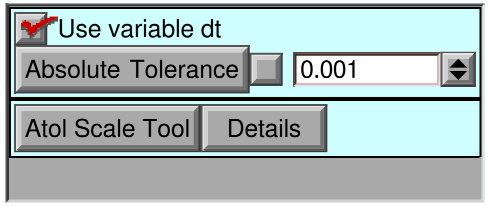
ChannelBuildGateGUI[0]forChannelBuild[0]
Close
Hide
States
Transitions
Properties
Select hh state or ks transition to change properties
C3
v
O2
C
v
C2
cai
O
O3
(0.25*C2 + O)
(0.25*C2 + O): 3 state, 2 transitions
Power
1
Fractional Conductance
C2 fraction
0.25
O fraction
1
Adjust
Run
aC2O
bC2O
C2 + cai <-> O (a, b) (KSTrans[29])
Display inf, tau
aC2O = A
ChannelBuild[0]managedKSChan[
Close
Hide
Properties
kca Density Mechanism
k ohmic ion current
ik (mA/cm2) = g_kca * (v - ek)
g = gmax * (0.25*C2 + O) * O2 * O3
Default gmax = 0 (S/cm2)
(0.25*C2 + O): 3 state, 2 transiti
O2: 2 state, 1 transitions
O3' = aO3*(1 - O3) - bO3*O3

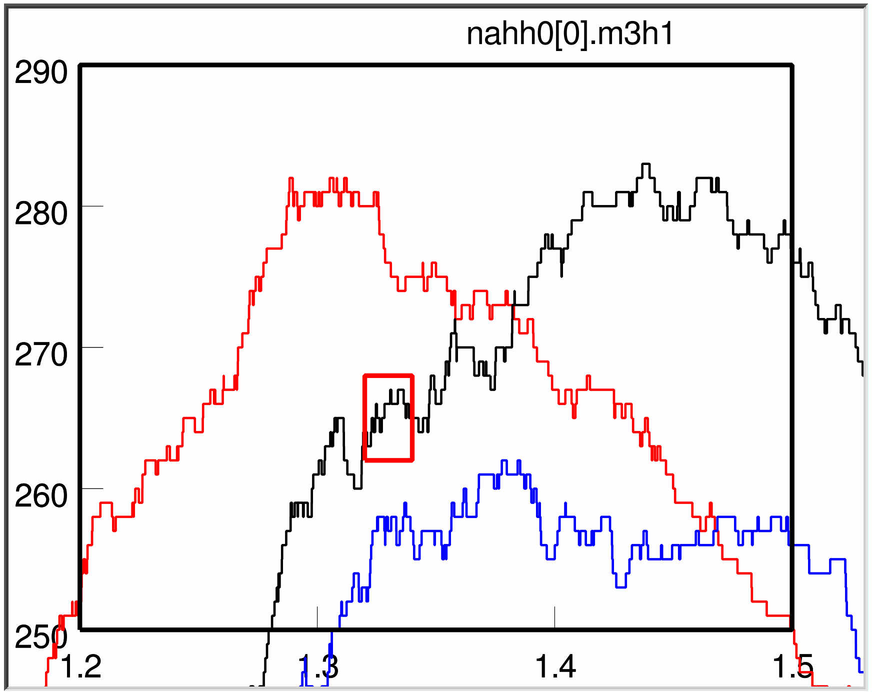


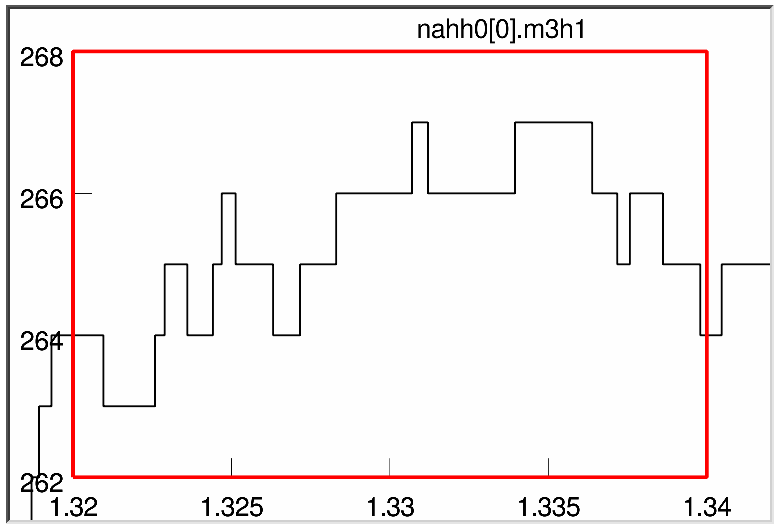
ChannelBuild[3]managedKSChan[3]
Close
Hide
Properties
nahh0 Point Process (Allow Single Channels)
na ohmic ion current
ina (mA/cm2) = nahh0.g * (v - ena)*(0.01/area)
g = gmax * m3h1
Default gmax = 0.12 (uS)
m3h1: 8 state, 10 transitions
SingleComp
Close
Hide
soma
pas
hh
nahh
khh
leak
PointProcessManager
Close
Hide
SelectPointProcess
Show
nahh0[0]
at:soma(0.5)
nahh0[0]
Nsingle
0
ChannelBuildGateGUI[0]forChannelBuild[3]
Close
Hide
States
Transitions
Properties
Select hh state or ks transition to change properties
m0h1
m1h1
m2h1
m3h1
m0h0
m1h0
m2h0
m3h0
m3h1
m3h1: 8 state, 10 transitions
Power
1
Fractional Conductance
m0h0 fraction
0
m1h0 fraction
0
Adjust
Run
m0h0 <-> m1h0 (a, b) (KSTrans[14])
Display inf, tau
am0h0m1h0 = A*x/(1 - exp(-x)) where x = k*(v - d)

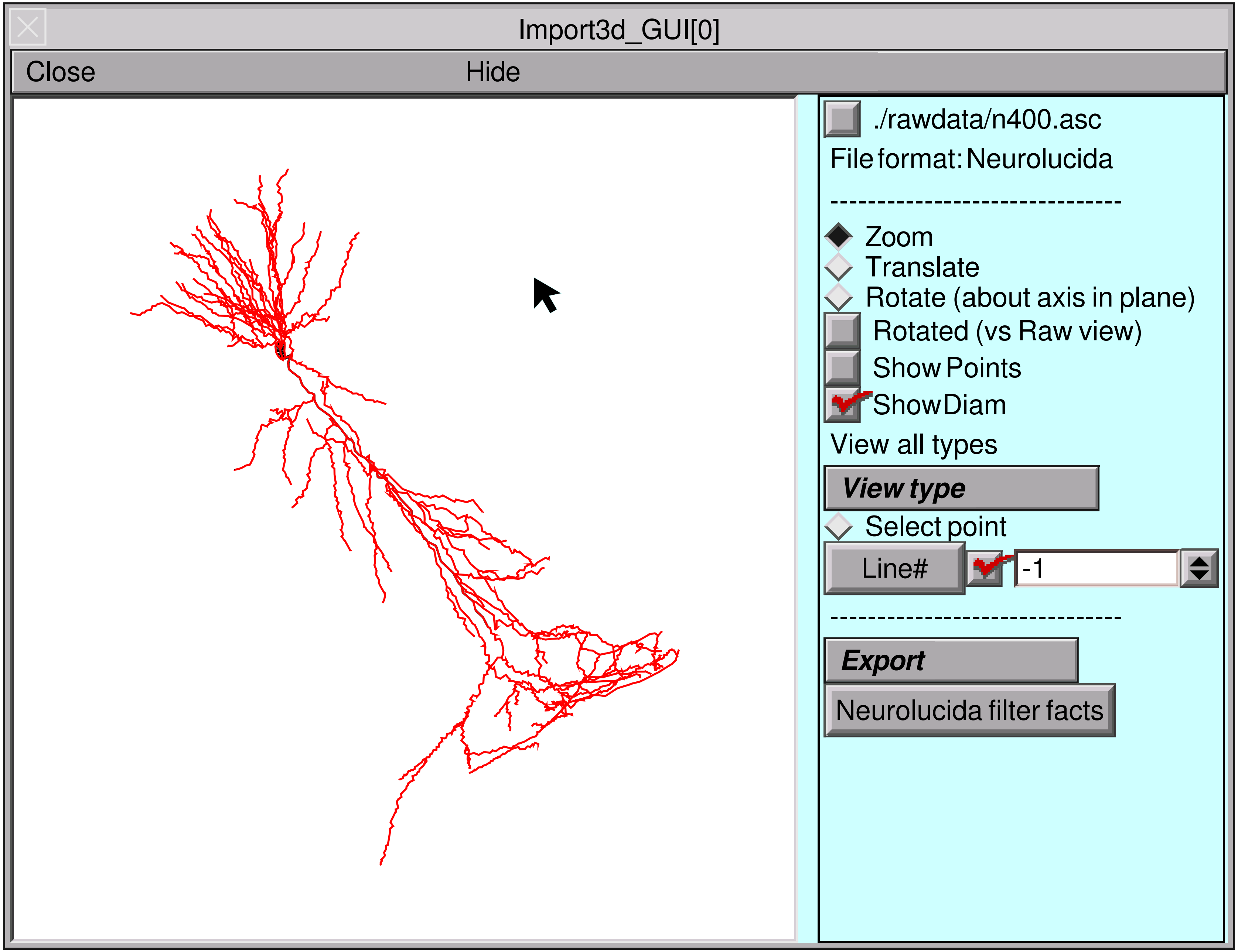

at:soma(0.5)
nahh0[0]
Nsingle
0
gmax (uS)
0.12
g (uS)
6.816e-08
Graph[0] x -0.5 : 5.5 y -92 : 52
v(.5)
Graph[1] x -0.5 : 5.5 y -0.03 : 0.33
nahh0[0].m3h1
at:soma(0.5)
nahh0[0]
Nsingle
1000
gmax (uS)
0.00012
g (uS)
0
Graph[0] Color/Brush x -0.5 : 5.5 y -92 : 52
v(.5)
Graph[1] Color/Brush x -0.5 : 5.5 y -30 : 330
nahh0[0].m3h1


nahh0[0].m3h1
20935 points
300
200
100
0
0
1
2
3
4
5


Use variable dt
Absolute Tolerance
0.001
Atol Scale Tool
Details


nahh0[0].m3h1
290
280
270
260
250
1.2
1.3
1.4
1.5

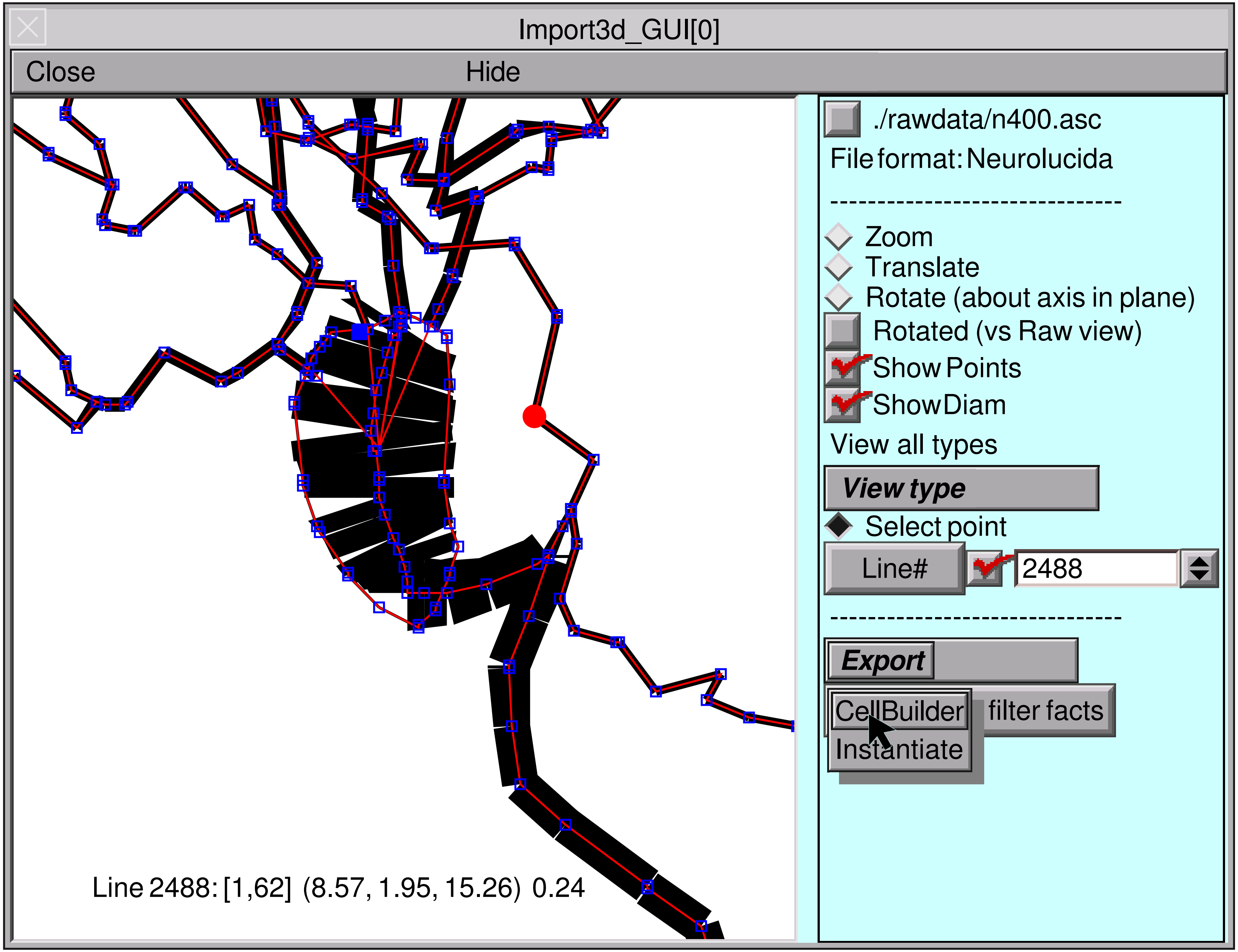

nahh0[0].m3h1
268
266
264
262
1.32
1.325
1.33
1.335
1.34



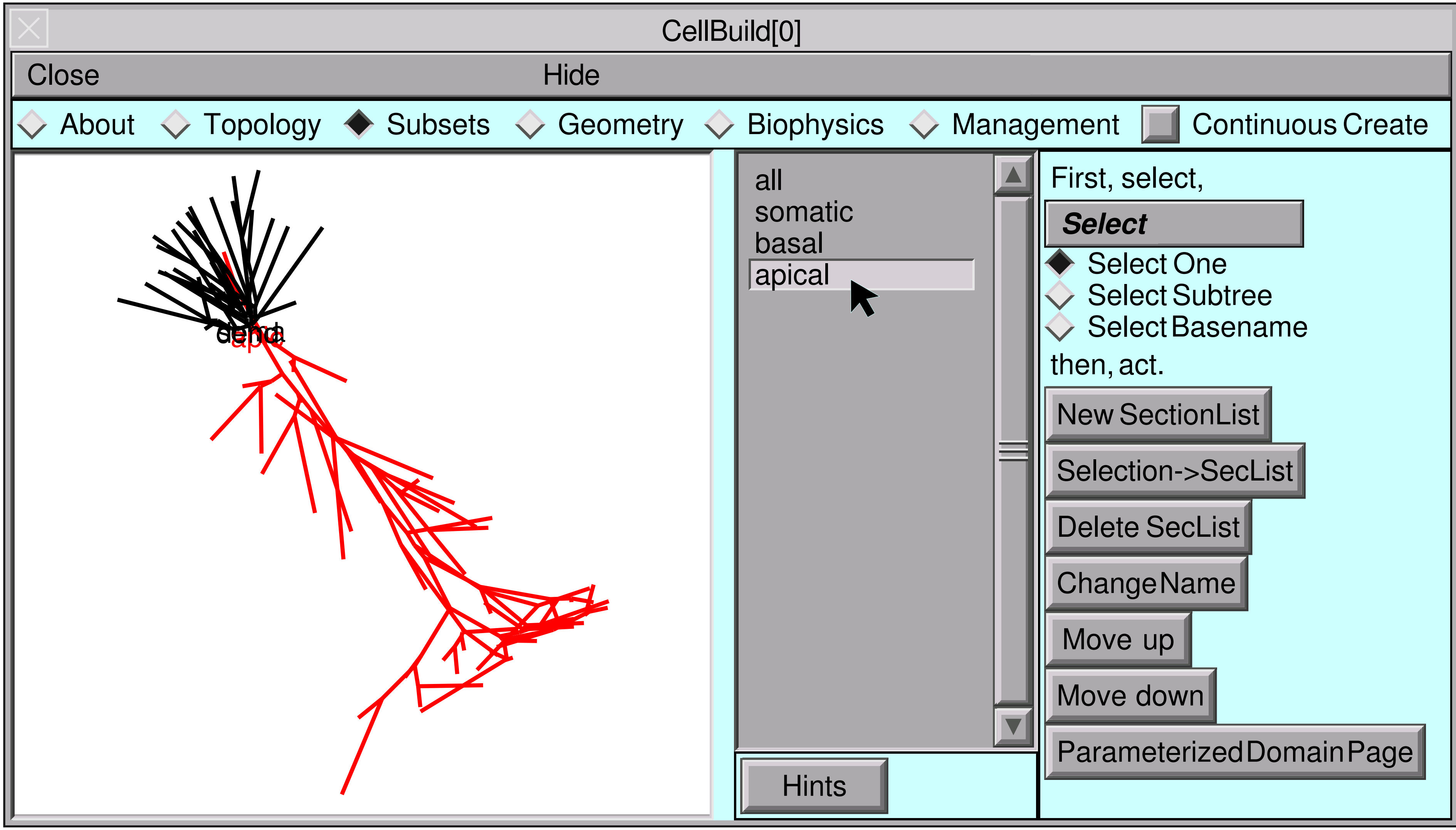
Import3d_GUI[0]
Close
Hide
./rawdata/n400.asc
File format: Neurolucida

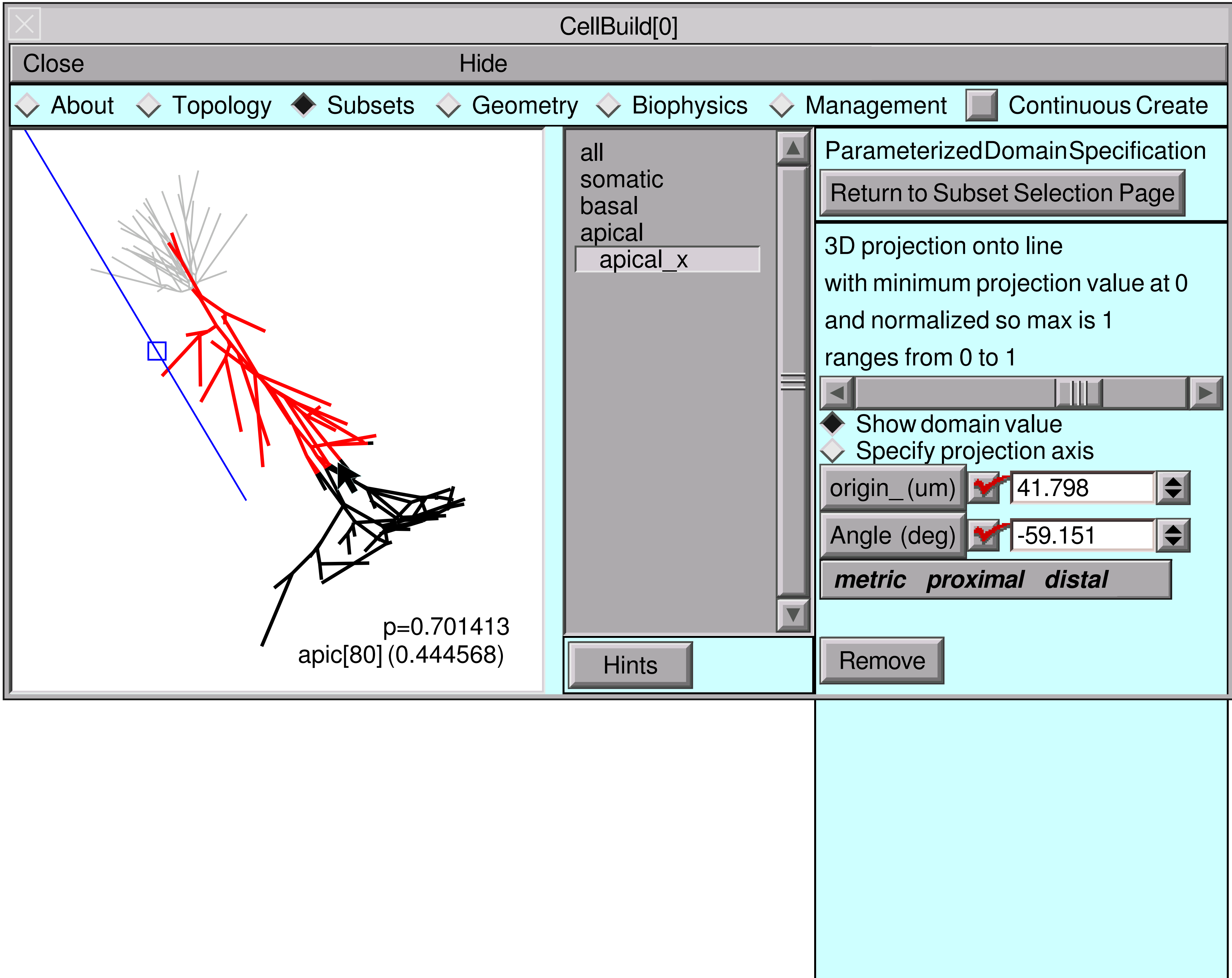
Zoom
Translate
Rotate (about axis in plane)
Rotated (vs Raw view)
Show Points
ShowDiam
View all types
View type
Select point
Line#
-1

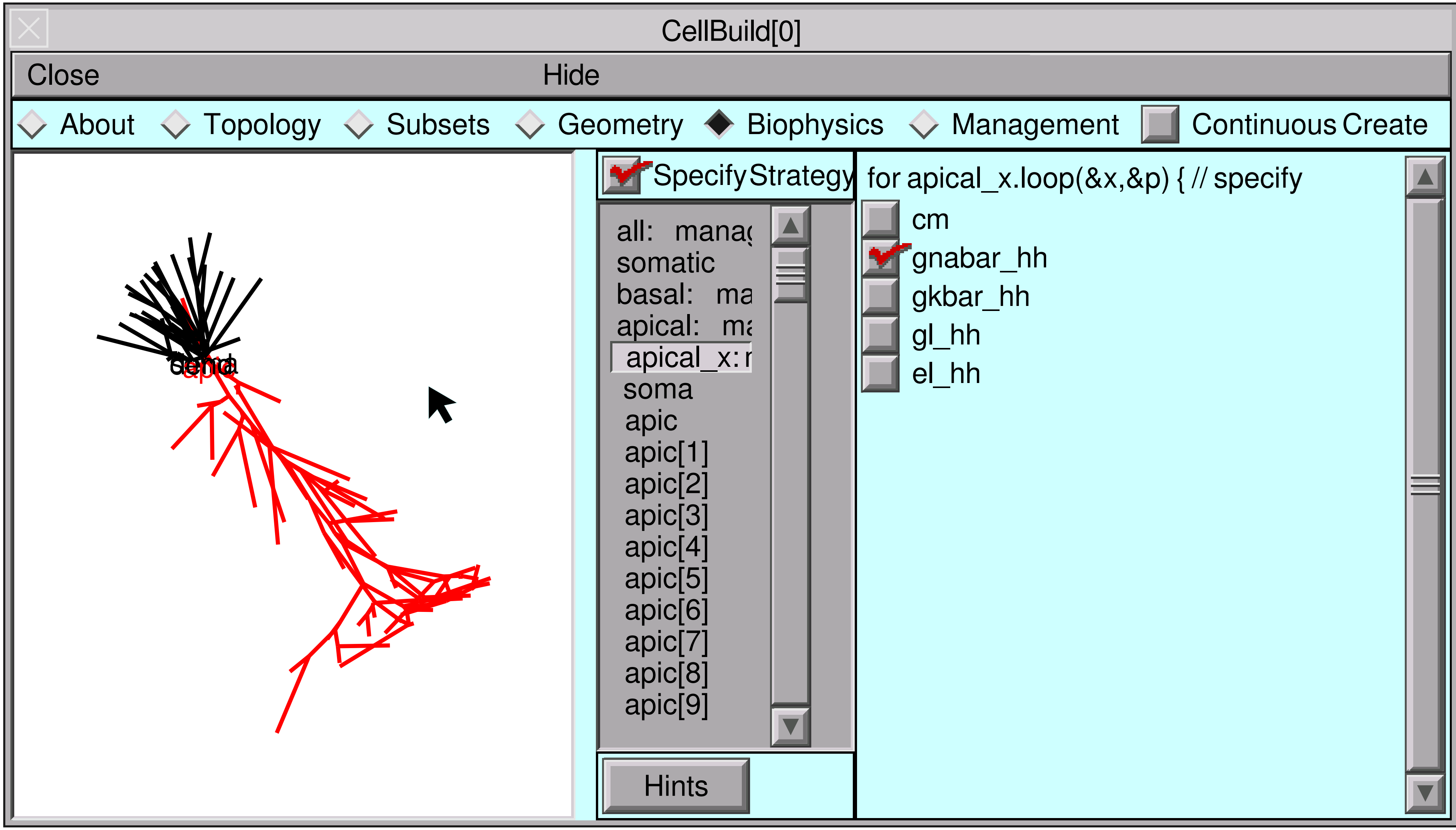
Export
Neurolucida filter facts

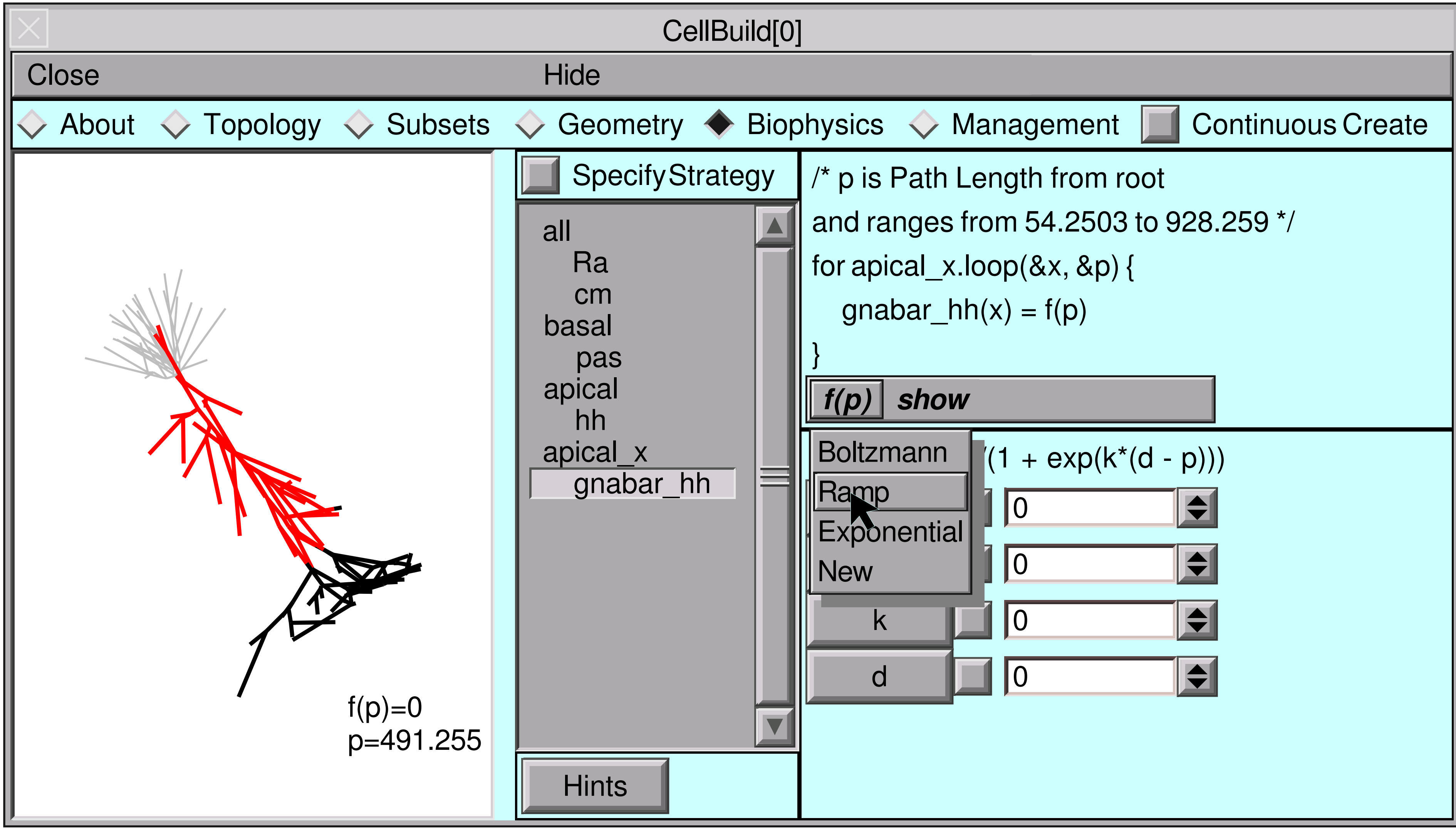


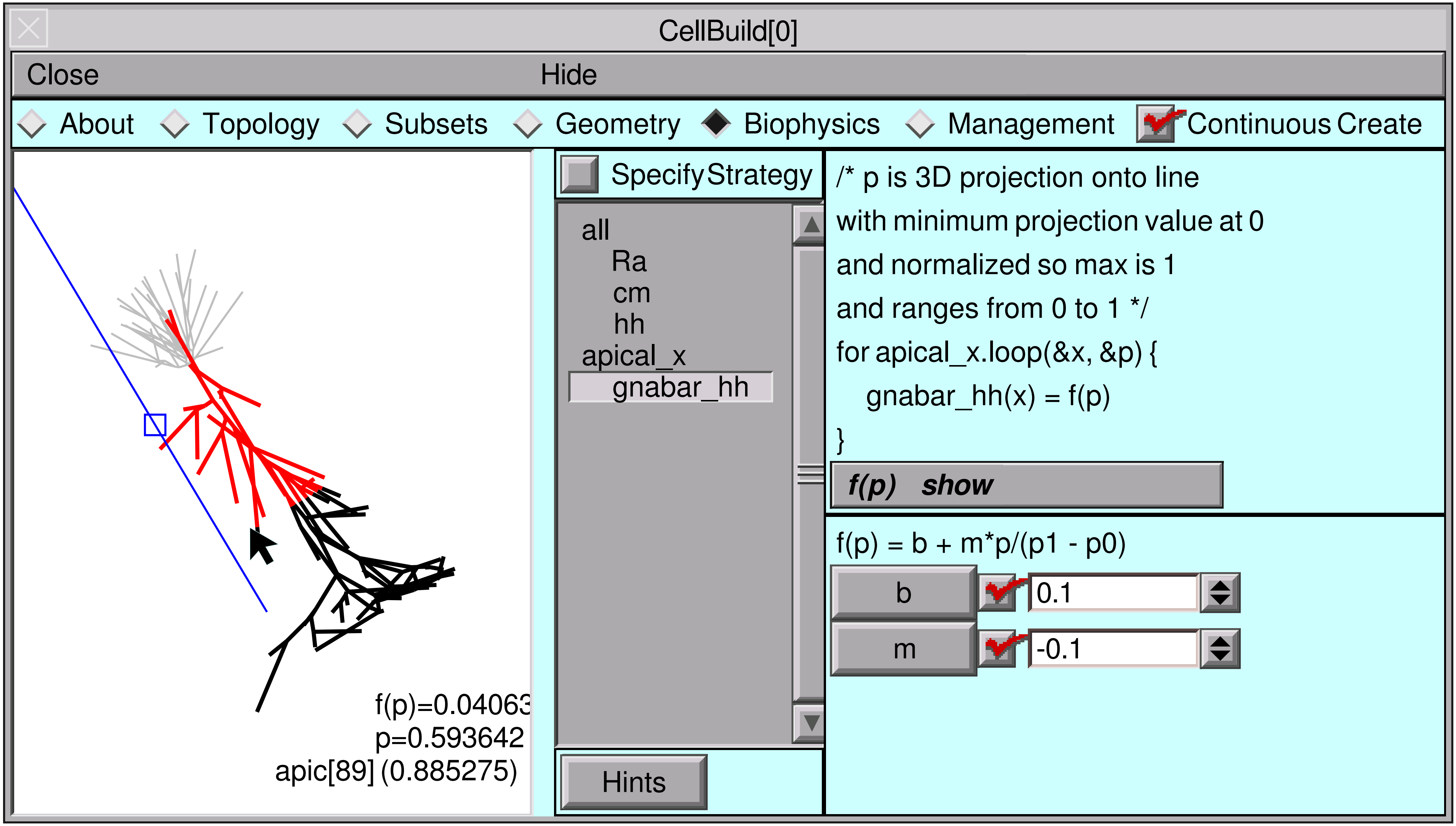
Import3d_GUI[0]
Close
Hide
./rawdata/n400.asc
File format: Neurolucida
Zoom
Translate
Rotate (about axis in plane)
Rotated (vs Raw view)
Show Points
ShowDiam
View all types
View type
Select point
Line#
2488
Export
CellBuilder
filter facts
Instantiate
Line 2488: [1,62] (8.57, 1.95, 15.26) 0.24

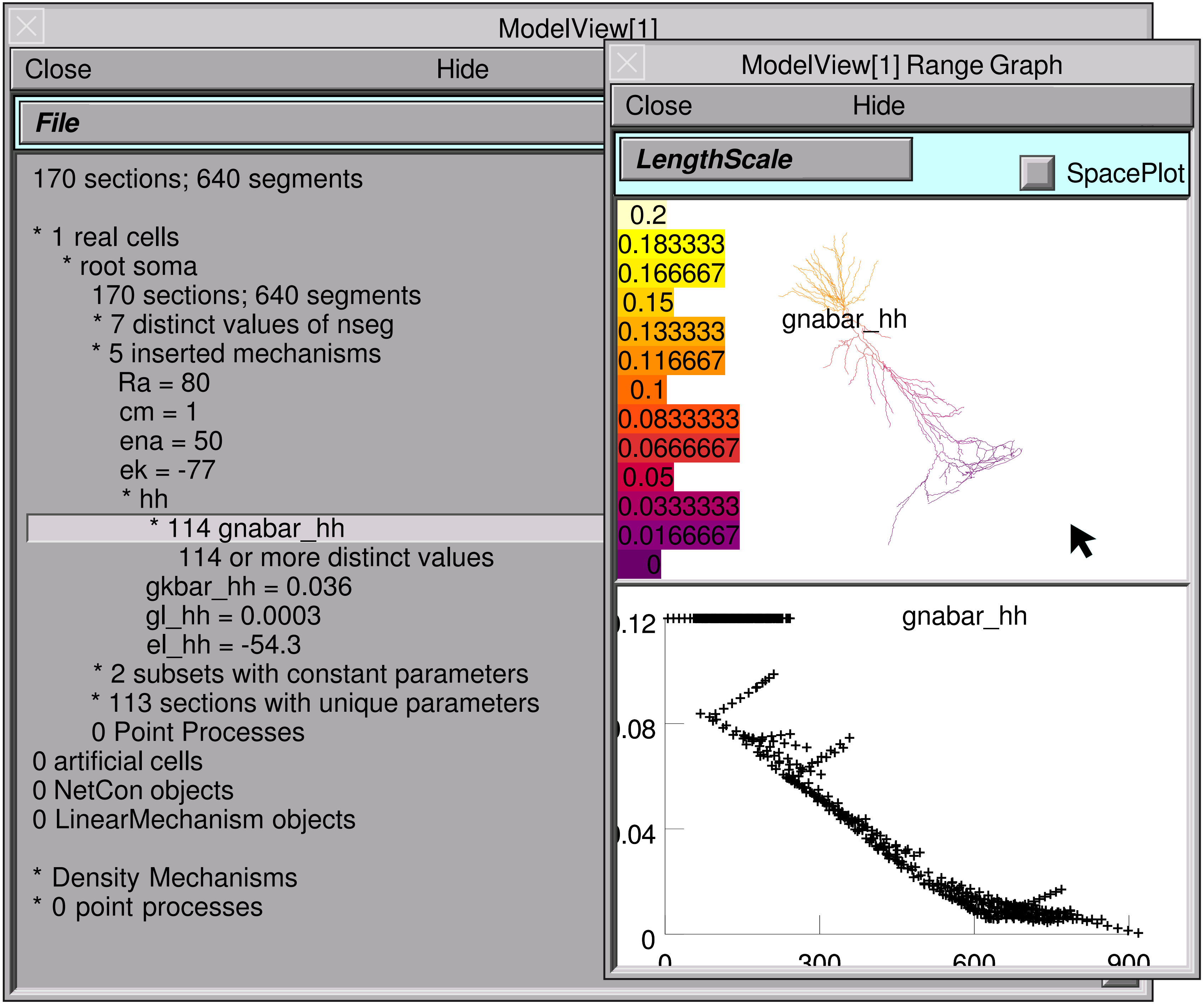

CellBuild[0]
Close
Hide
About
Topology
Subsets
Geometry
Biophysics
Management
Continuous Create
all
somatic
basal
apical
Hints
First, select,
Select
Select One
Select Subtree
Select Basename
then, act.
New SectionList
Selection->SecList
Delete SecList
ChangeName
Move up
Move down
ParameterizedDomainPage

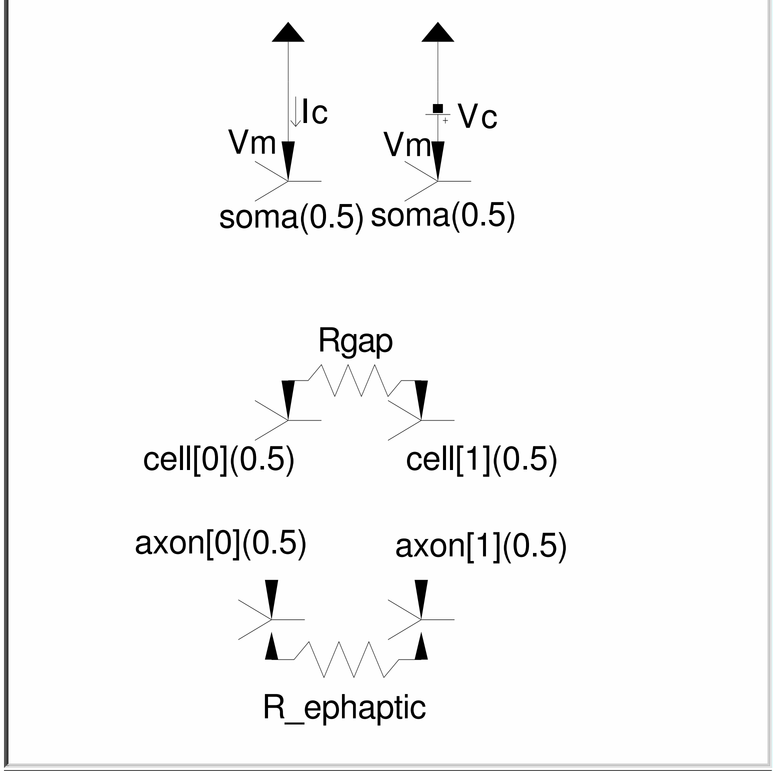

CellBuild[0]
Close
Hide
About
Topology
Subsets
Geometry
Biophysics
Management
Continuous Create
all
somatic
basal
apical
apical_x
ParameterizedDomainSpecification
Return to Subset Selection Page
3D projection onto line
with minimum projection value at 0
and normalized so max is 1
ranges from 0 to 1
Show domain value
Specify projection axis
origin_(um)
41.798
Angle (deg)
-59.151
metric proximal distal
p=0.701413
apic[80] (0.444568)
Hints
Remove

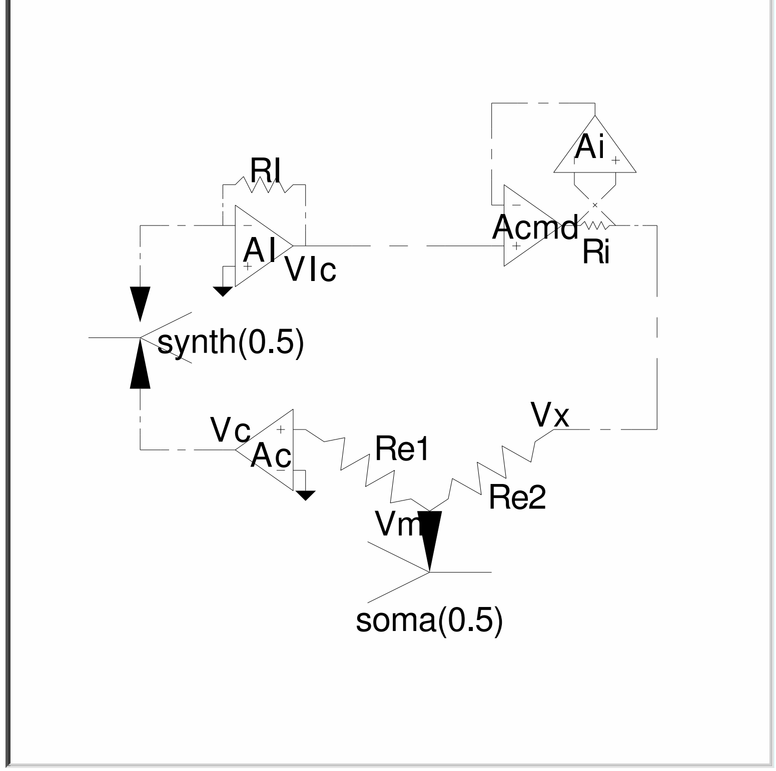

CellBuild[0]
Close
Hide
About
Topology
Subsets
Geometry
Biophysics
Management
Continuous Create
SpecifyStrategy
all: manag
somatic
basal: ma
apical: ma
apical_x: r
soma
apic
apic[1]
apic[2]
apic[3]
apic[4]
apic[5]
apic[6]
apic[7]
apic[8]
apic[9]
Hints
for apical_x.loop(&x,&p) { // specify
cm
gnabar_hh
gkbar_hh
gl_hh
el_hh

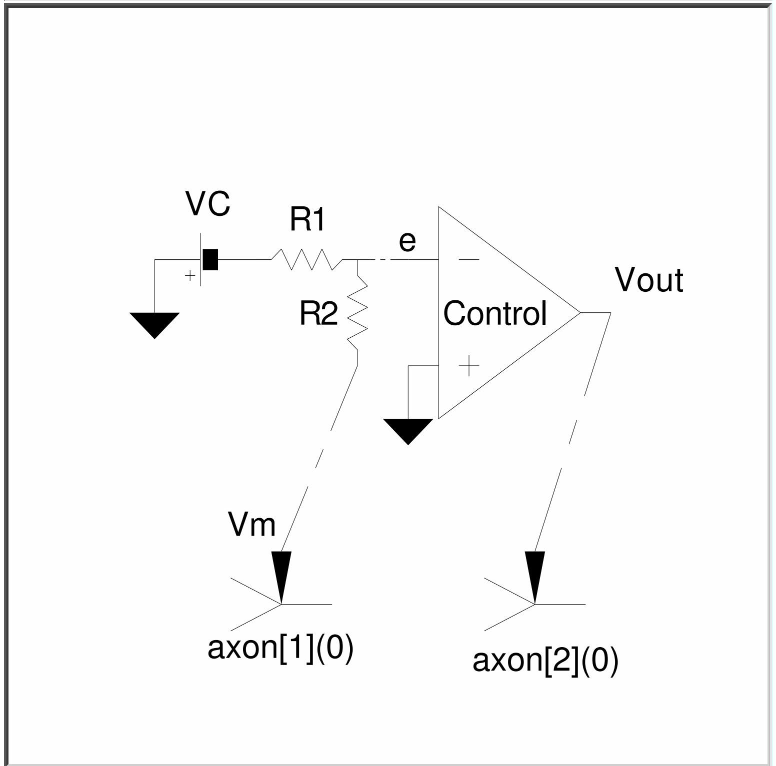

CellBuild[0]
Close
Hide
About
Topology
Subsets
Geometry
Biophysics
Management
Continuous Create
Specify Strategy
all
Ra
cm
basal
pas
apical
hh
apical_x
gnabar_hh
Hints
/* p is Path Length from root
and ranges from 54.2503 to 928.259 */
for apical_x.loop(&x, &p) {
gnabar_hh(x) = f(p)
}
f(p)
show
Boltzmann
Ramp
Exponential
New
/(1 + exp(k*(d - p)))
k
d
0
0
0
0
f(p)=0
p=491.255

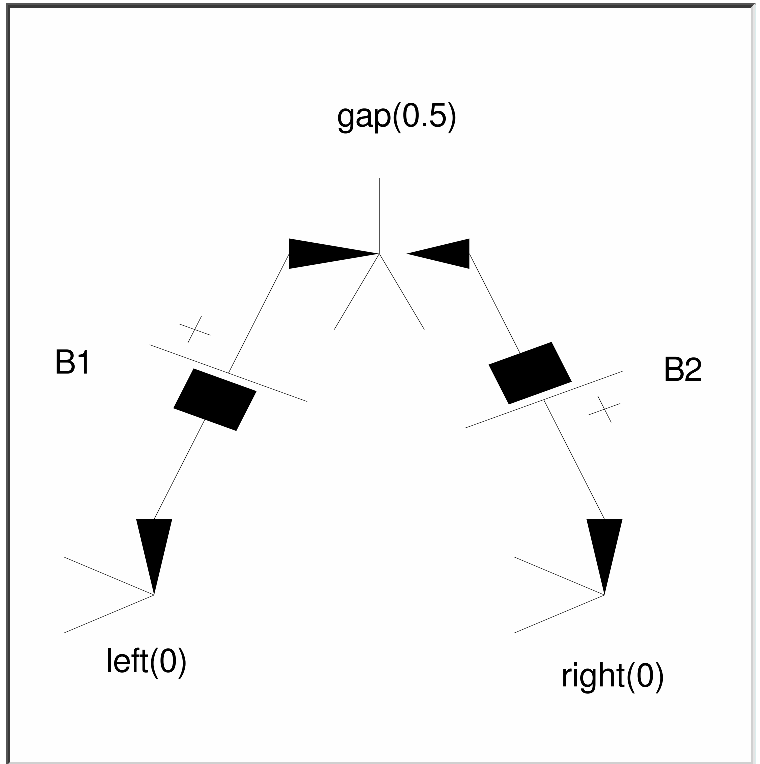

CellBuild[0]
Close
Hide
About
Topology
Subsets
Geometry
Biophysics
Management
Continuous Create
SpecifyStrategy
all
Ra
cm
hh
apical_x
gnabar_hh
Hints
/* p is 3D projection onto line
with minimum projection value at 0
and normalized so max is 1
and ranges from 0 to 1 */
for apical_x.loop(&x, &p) {
gnabar_hh(x) = f(p)
}
f(p) show
f(p) = b + m*p/(p1 - p0)
b
0.1
m
-0.1
p=0.593642
apic[89] (0.885275)

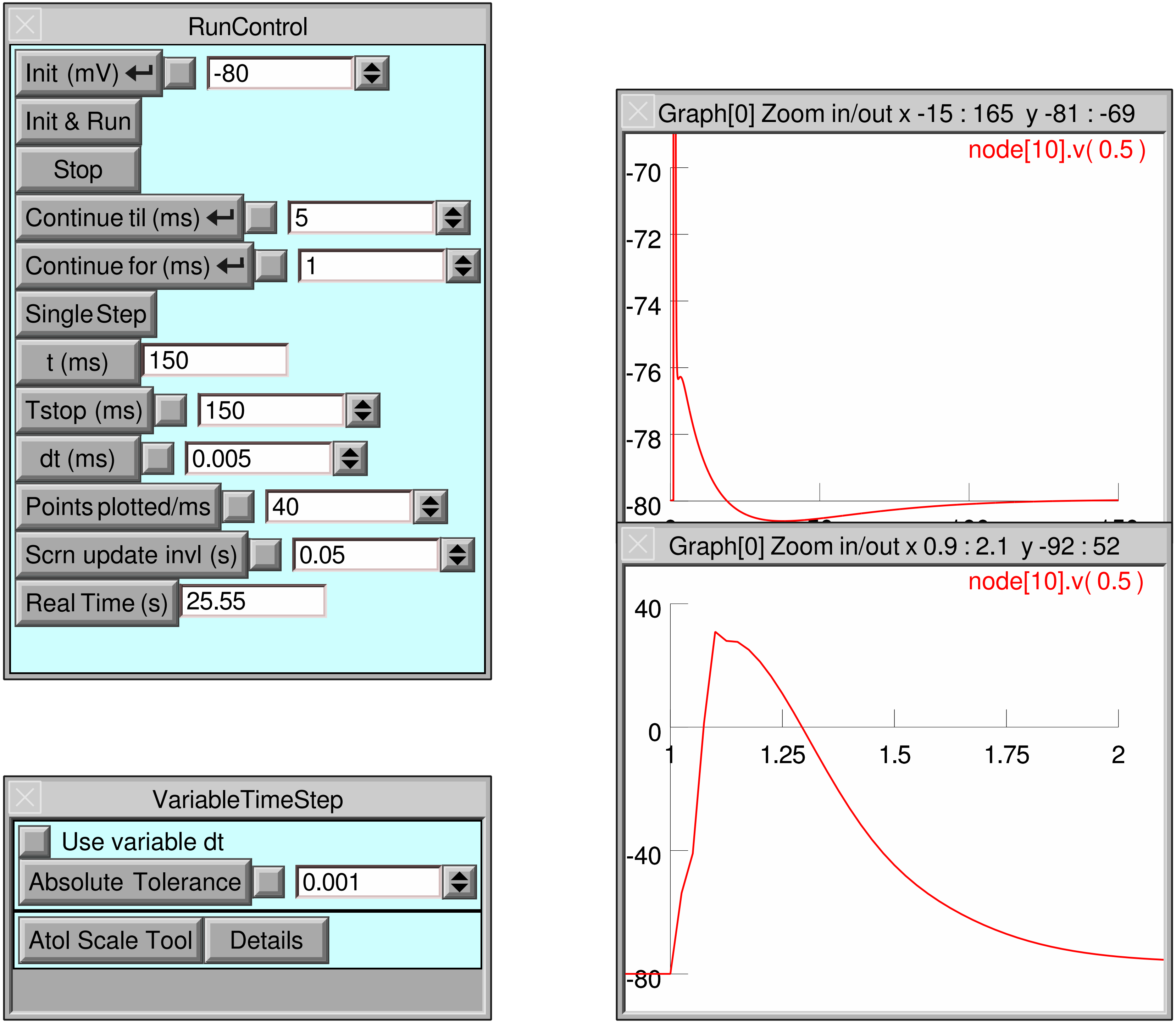

ModelView[1]
Close
Hide
File
170 sections; 640 segments
* 1 real cells
* root soma
170 sections; 640 segments
* 7 distinct values of nseg
* 5 inserted mechanisms
Ra = 80
cm = 1
ena = 50
ek = -77
* hh
* 114 gnabar_hh
114 or more distinct values
gkbar_hh = 0.036
gl_hh = 0.0003
el_hh = -54.3
* 2 subsets with constant parameters
* 113 sections with unique parameters
0 Point Processes
0 artificial cells
0 NetCon objects
0 LinearMechanism objects
* Density Mechanisms
* 0 point processes
ModelView[1] Range Graph
Close
Hide
LengthScale
SpacePlot
0.2
0.183333
0.166667
0.15
0.133333
0.116667
0.1
0.0833333
0.0666667
0.05
0.0333333
0.0166667
0
gnabar_hh
gnabar_hh
.12
.08
.04
0
0
300
600
900

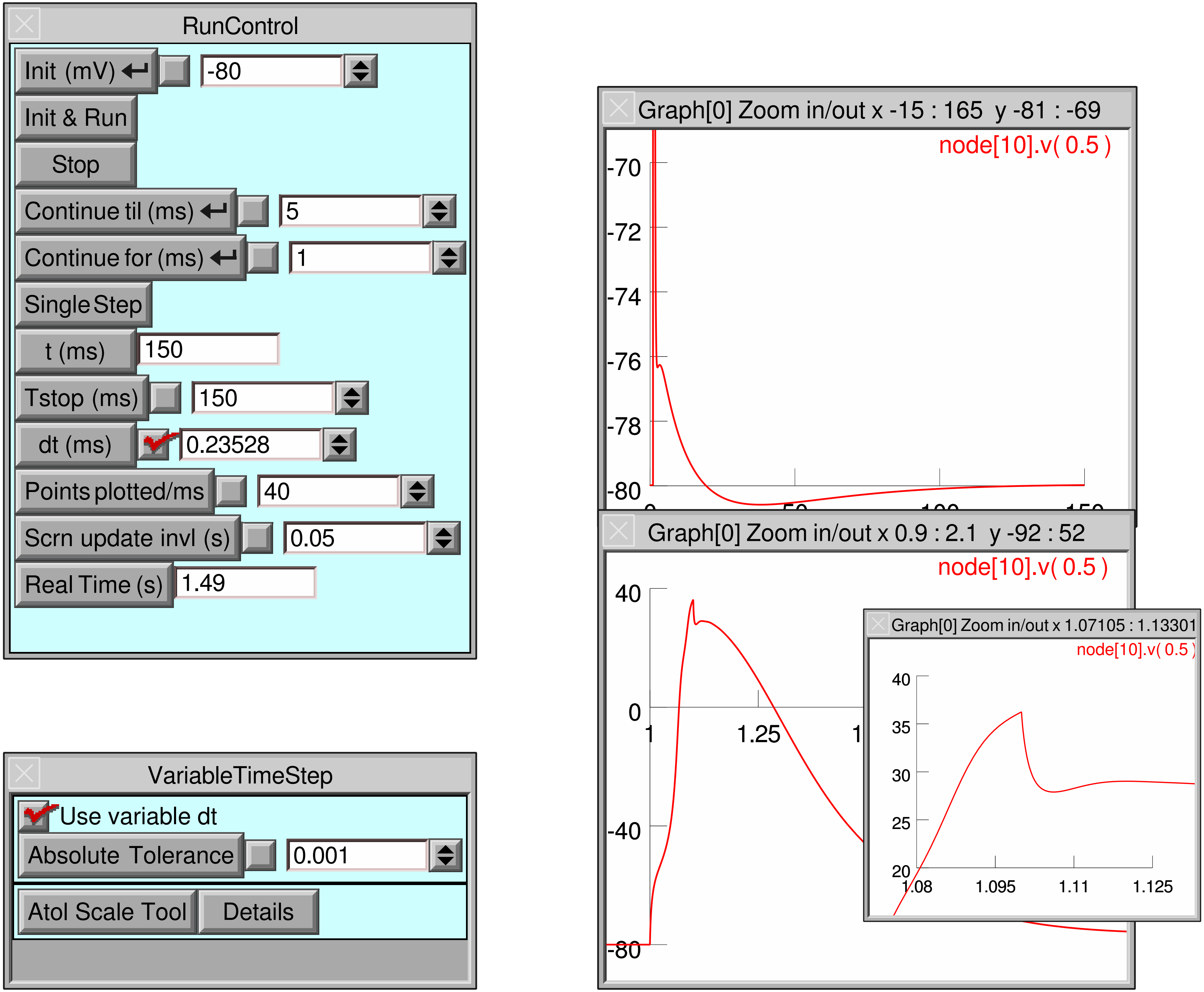

Ic
Vc
Vm
Vm
soma(0.5)
soma(0.5)
Rgap
cell[0](0.5)
cell[1](0.5)
axon[0](0.5)
axon[1](0.5)
R_ephaptic


Ai
RI
AI
Acmd
Ri
VIc
synth(0.5)
Vc
Ac
Re1
Vx
Re2
Vm
soma(0.5)

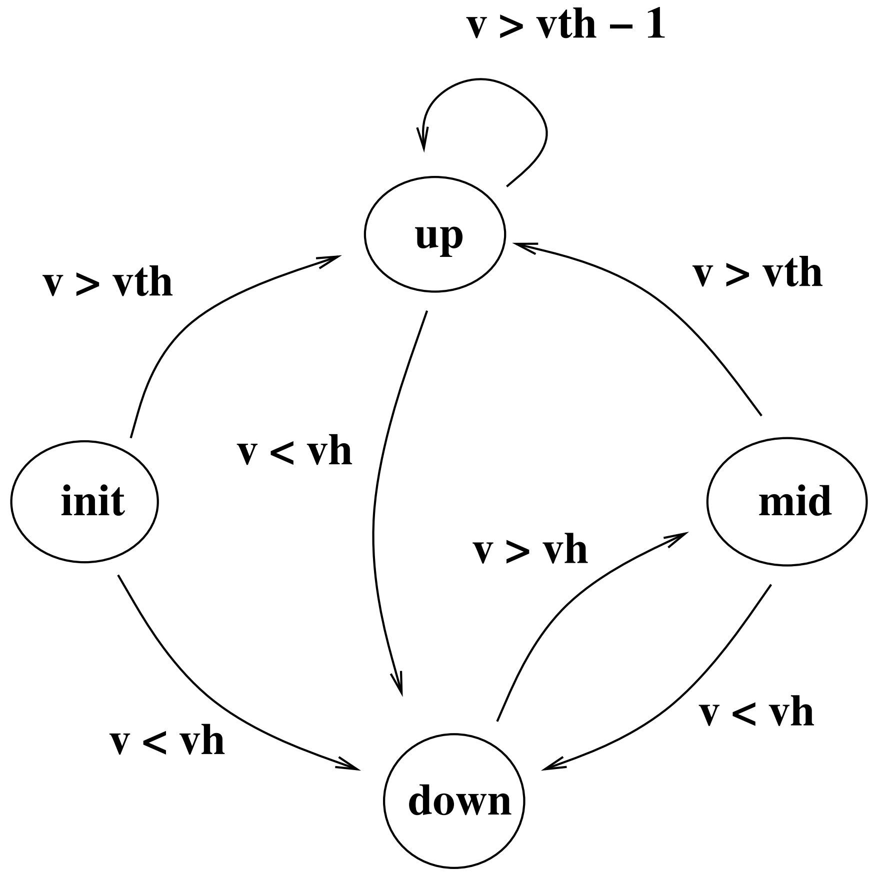

VC
R1
e
Vout
R2
Control
Vm
axon[1](0)
axon[2](0)


gap(0.5)
B1
B2
left(0)
right(0)

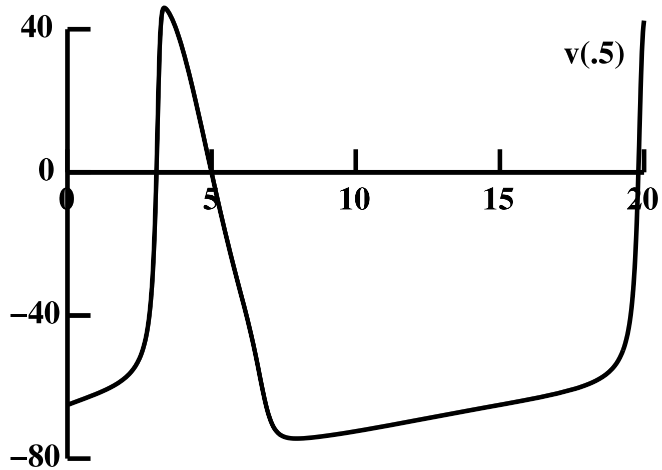

RunControl
Init (mV)
-80
Init & Run
Stop
Continue til (ms)
5
Continue for (ms)
1
Single Step
t (ms)
150
Tstop (ms)
150
dt (ms)
0.005
Points plotted/ms
40
Scrn update invl (s)
0.05
Real Time (s)
25.55
VariableTimeStep
Use variable dt
Absolute Tolerance
0.001
Atol Scale Tool
Details
Graph[0] Zoom in/out x -15 : 165 y -81 : -69
node[10].v(0.5)
-70
-72
-74
-76
-78
-80
Graph[0] Zoom in/out x 0.9 : 2.1 y -92 : 52
node[10].v(0.5)
40
0
-40
-80
1
1.25
1.5
1.75
2


RunControl
Init (mV)
-80
Init & Run
Stop
Continue til (ms)
5
Continue for (ms)
1
Single Step
t (ms)
150
Tstop (ms)
150
dt (ms)
0.23528
Points plotted/ms
40
Scrn update invl (s)
0.05
Real Time (s)
1.49
VariableTimeStep
Use variable dt
Absolute Tolerance
0.001
Atol Scale Tool
Details
Graph[0] Zoom in/out x -15 : 165 y -81 : -69
node[10].v(0.5)
-70
-72
-74
-76
-78
-80
Graph[0] Zoom in/out x 0.9 : 2.1 y -92 : 52
node[10].v(0.5)
40
0
-40
-80
1
1.25
Graph[0] Zoom in/out x 1.07105 : 1.13301
node[10].v(0.5)
40
35
30
25
20
1.08
1.095
1.11
1.125

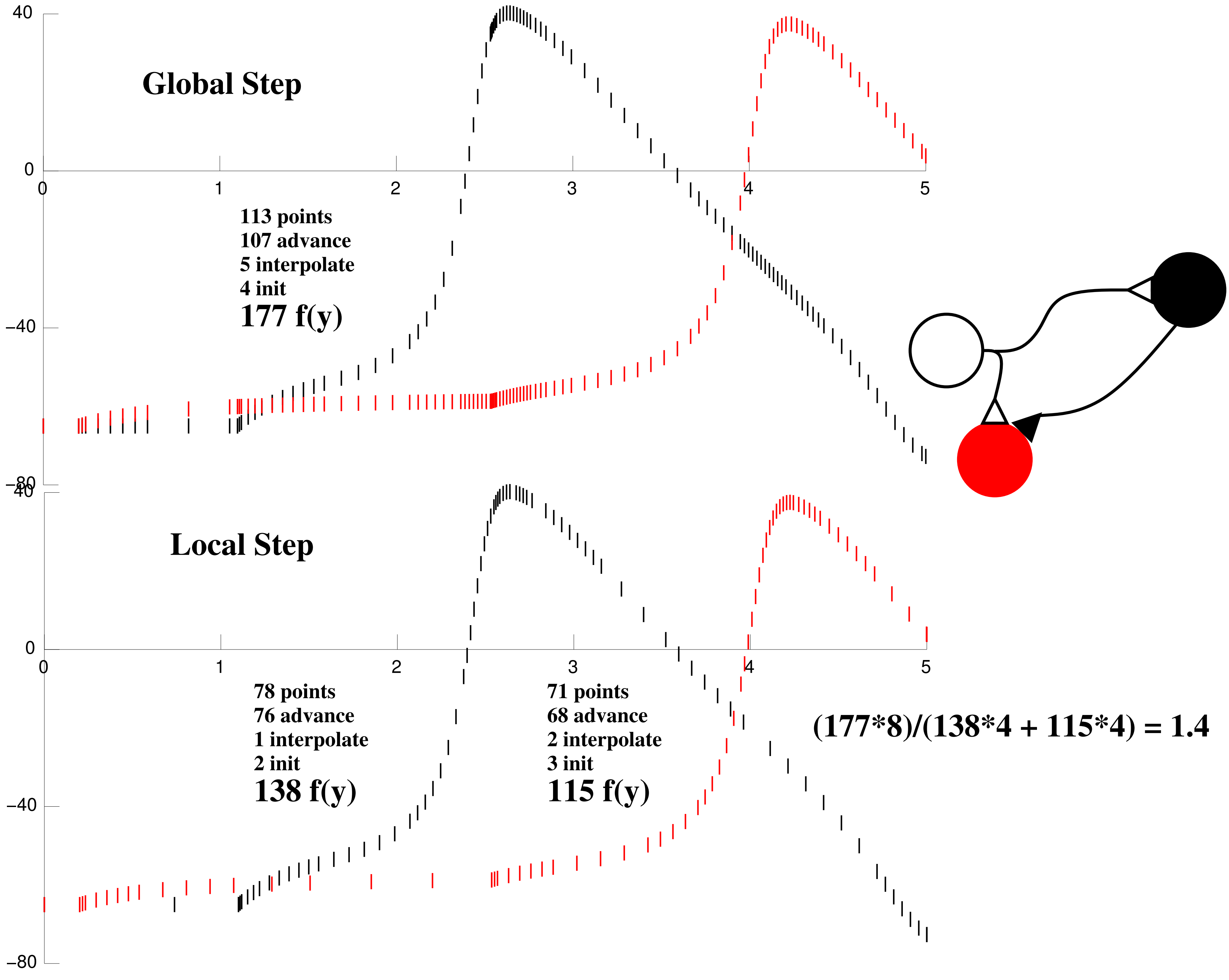
```
INITIAL {
  net_send(0, init)
}

NET_RECEIVE (w) {
  if (flag == init) {
    WATCH (v < vh) down
    WATCH (v > vth) up
  }
  if (flag == mid) {
    WATCH (v < vh) down
    WATCH (v > vth) up
  }
  if (flag == down) {
    WATCH (v > vh) mid
  }
  if (flag == up) {
    WATCH (v < vh) down
    WATCH (v > vth−1) up
  }
}
```



init t=0 v=−65
up t=2.925 vth=−35 v=−34.8438
down t=6.8 vh=−60 v=−60.098
mid t=17.875 vh=−60 v=−59.9339
up t=19.675 vth=−35 v=−34.6043

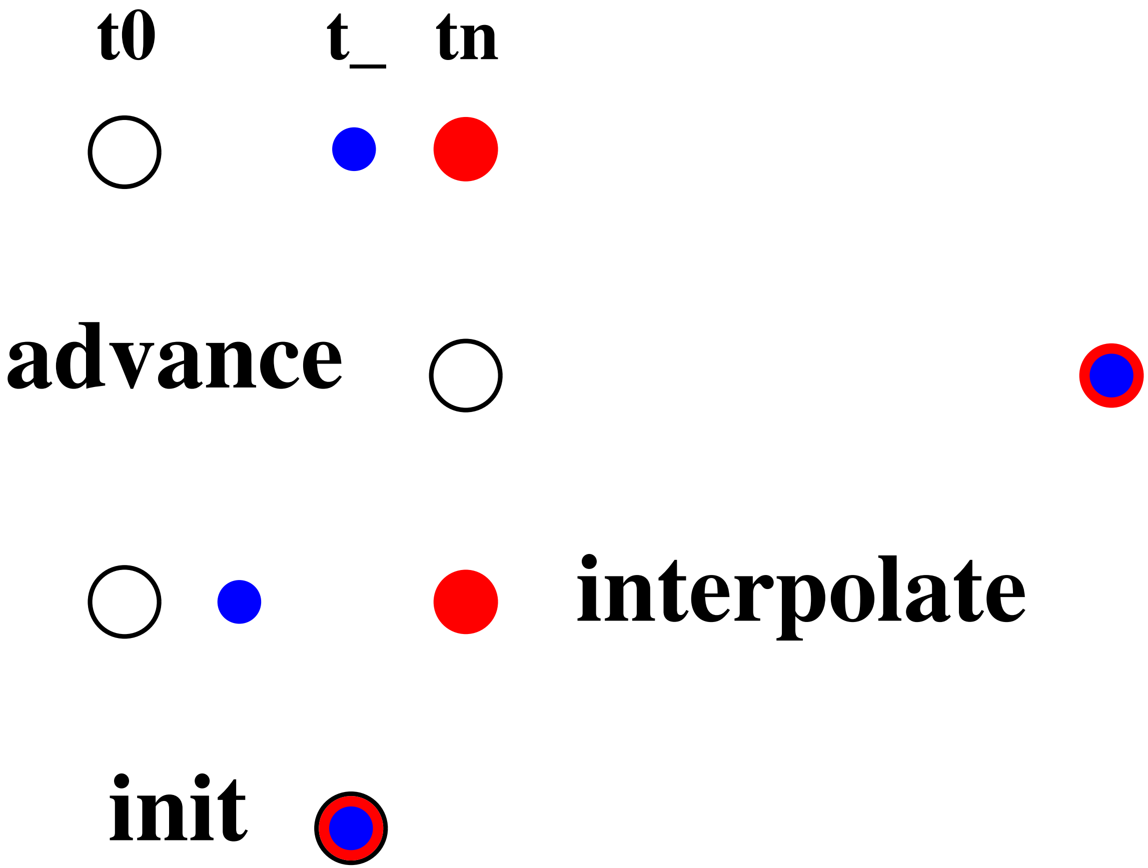


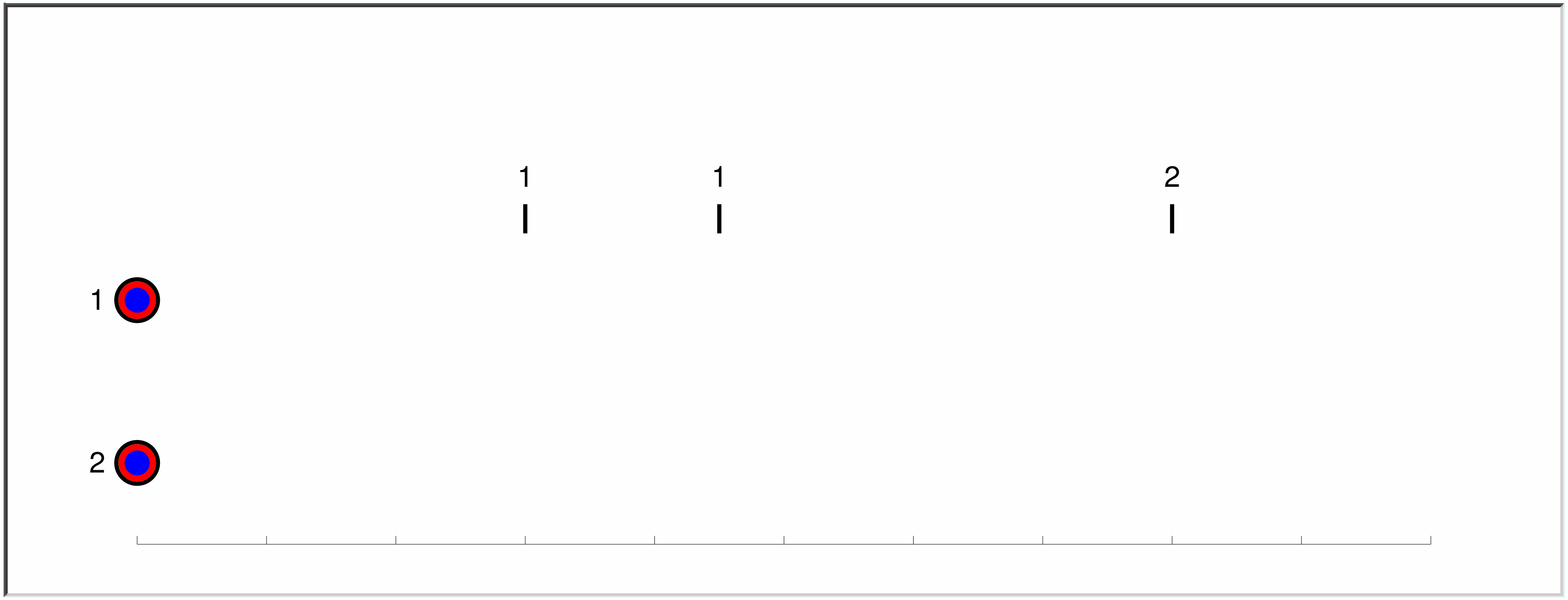
init t=0 v=−65
up t=2.90163 vth=−35 v=−35.0412
down t=6.74939 vh=−60 v=−60.0083
mid t=17.7923 vh=−60 v=−60.0002
up t=19.5997 vth=−35 v=−35.0351



Global Step
113 points
107 advance
5 interpolate
4 init
177 f(y)
Local Step
78 points
76 advance
1 interpolate
2 init
138 f(y)
71 points
68 advance
2 interpolate
3 init
115 f(y)
(177*8)/(138*4 + 115*4) = 1.4
40
0
−40
−80
0
1
2
3
4
5

One integrator instance per cell





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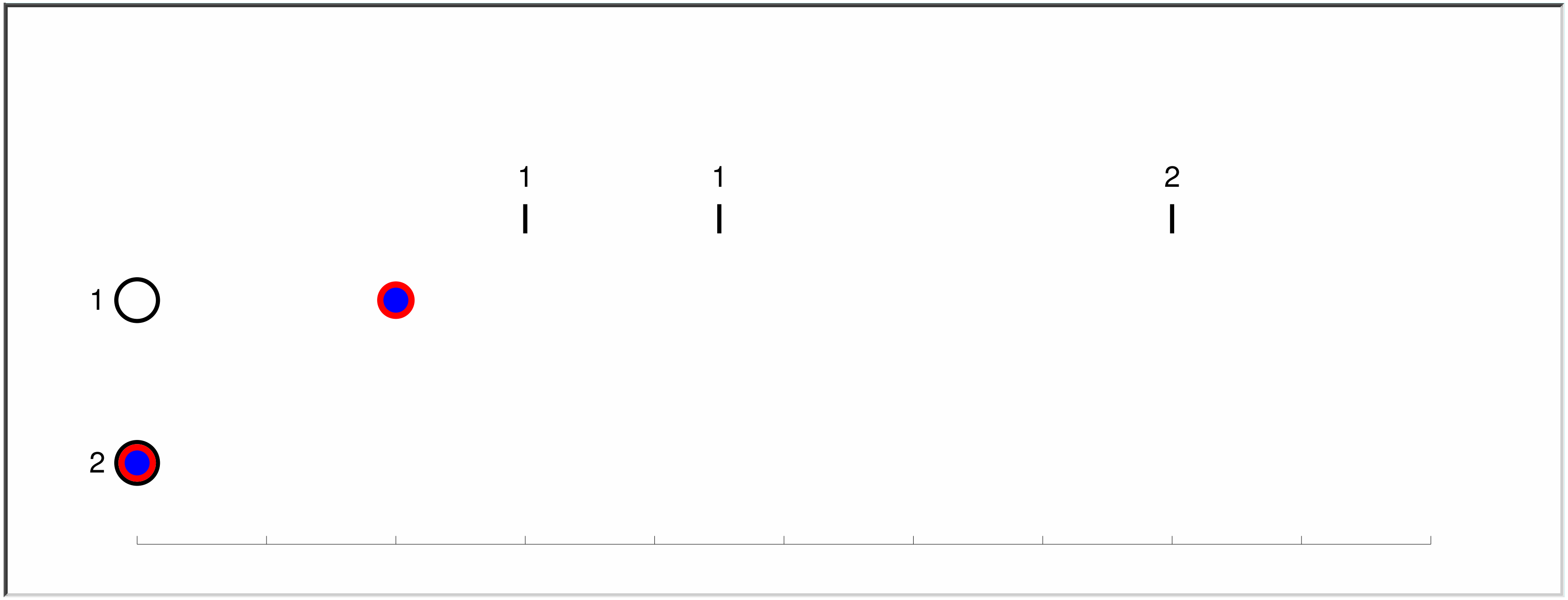

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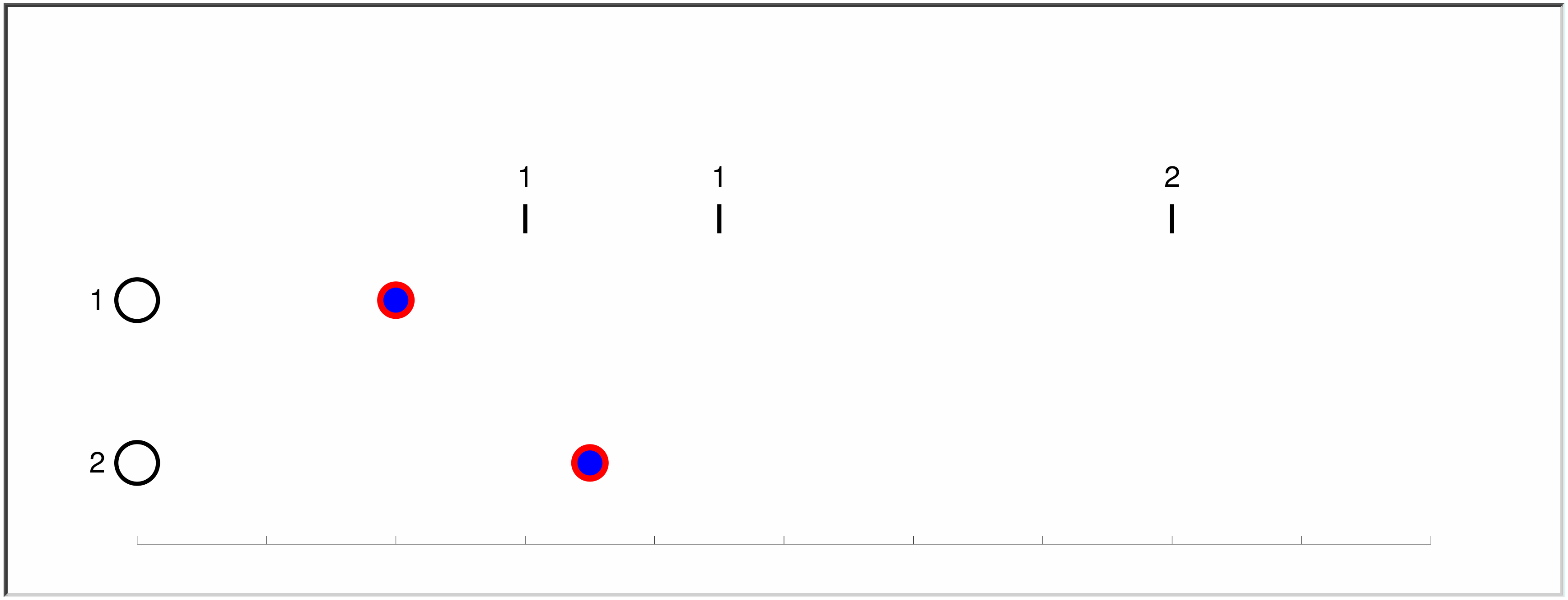

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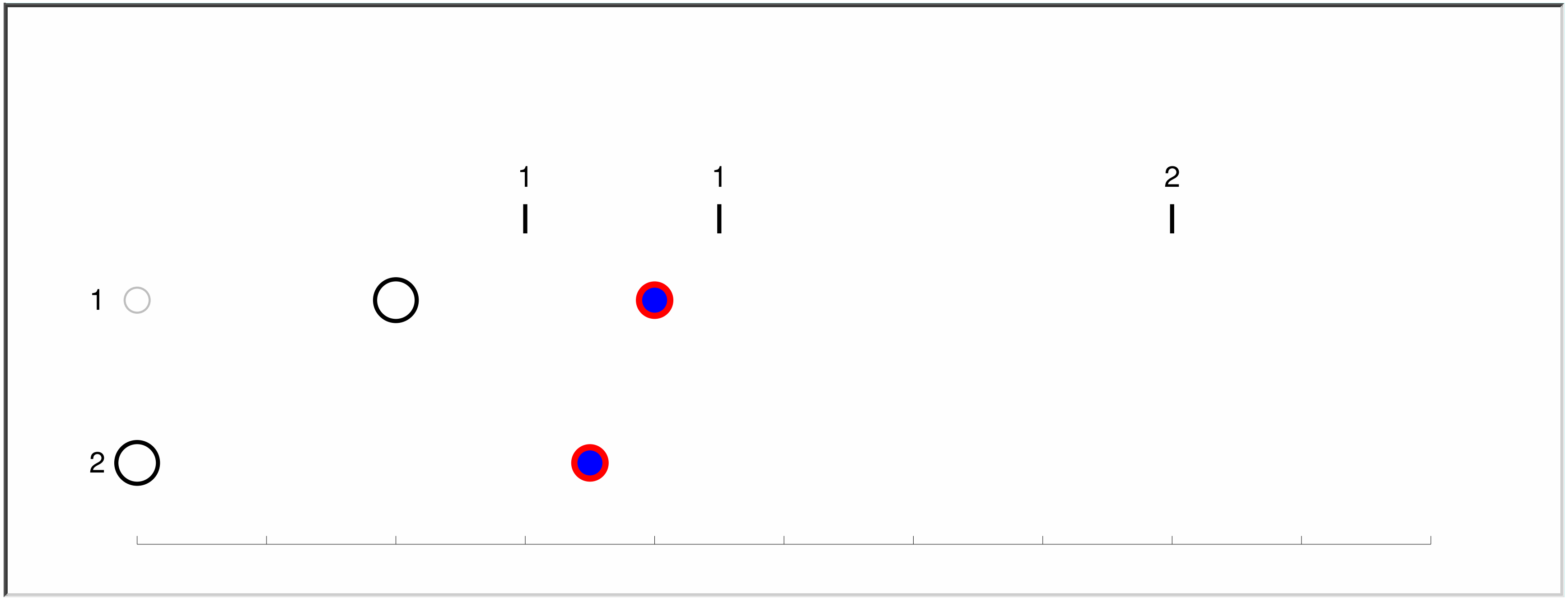
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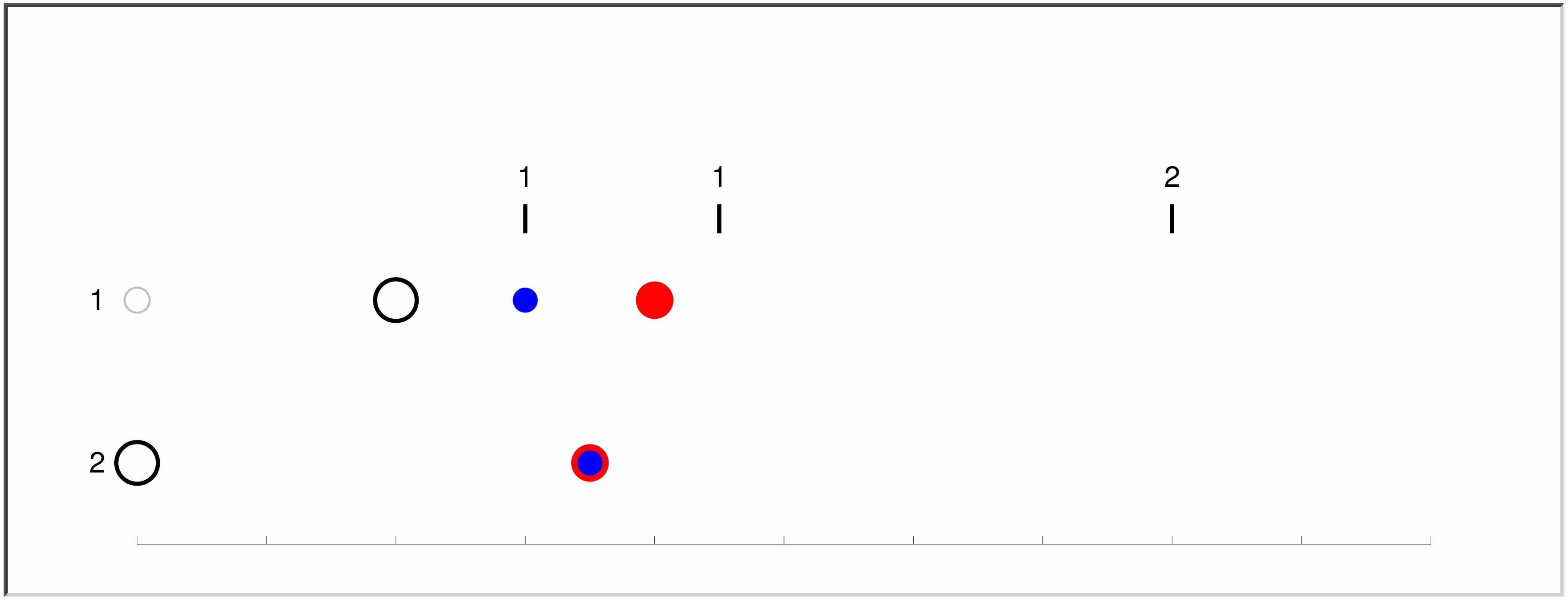
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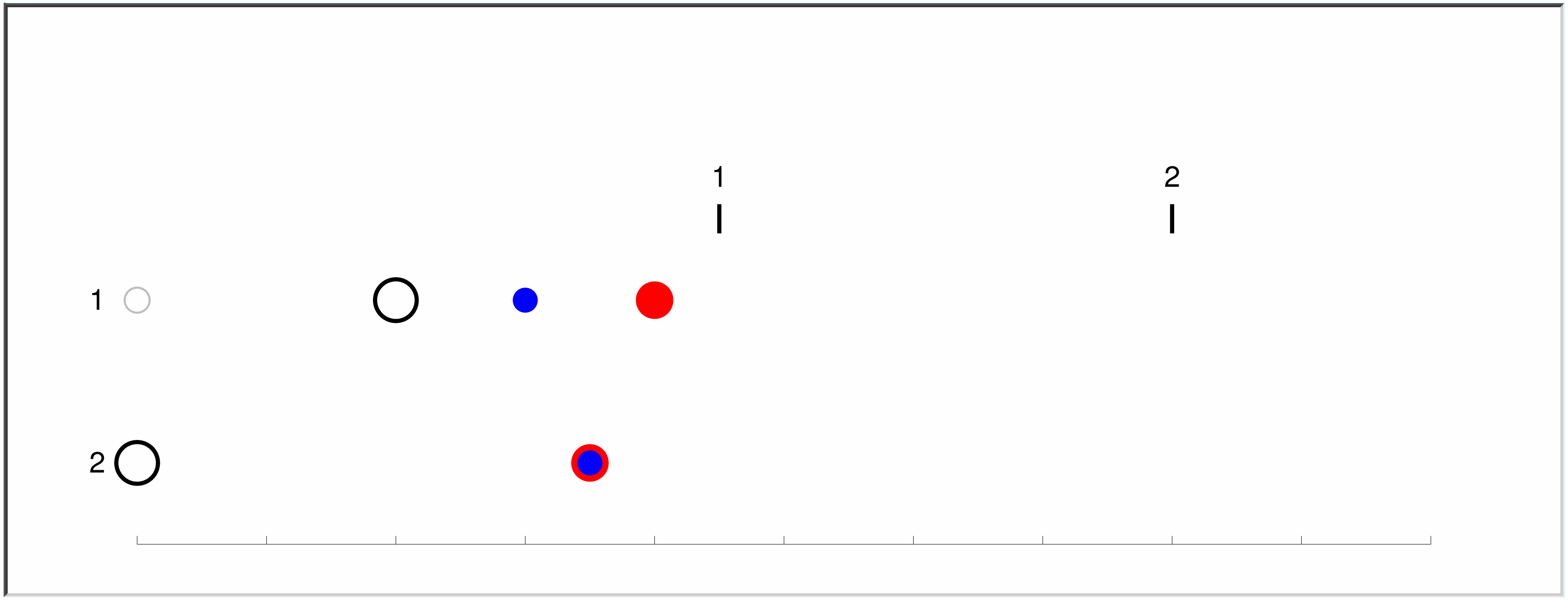
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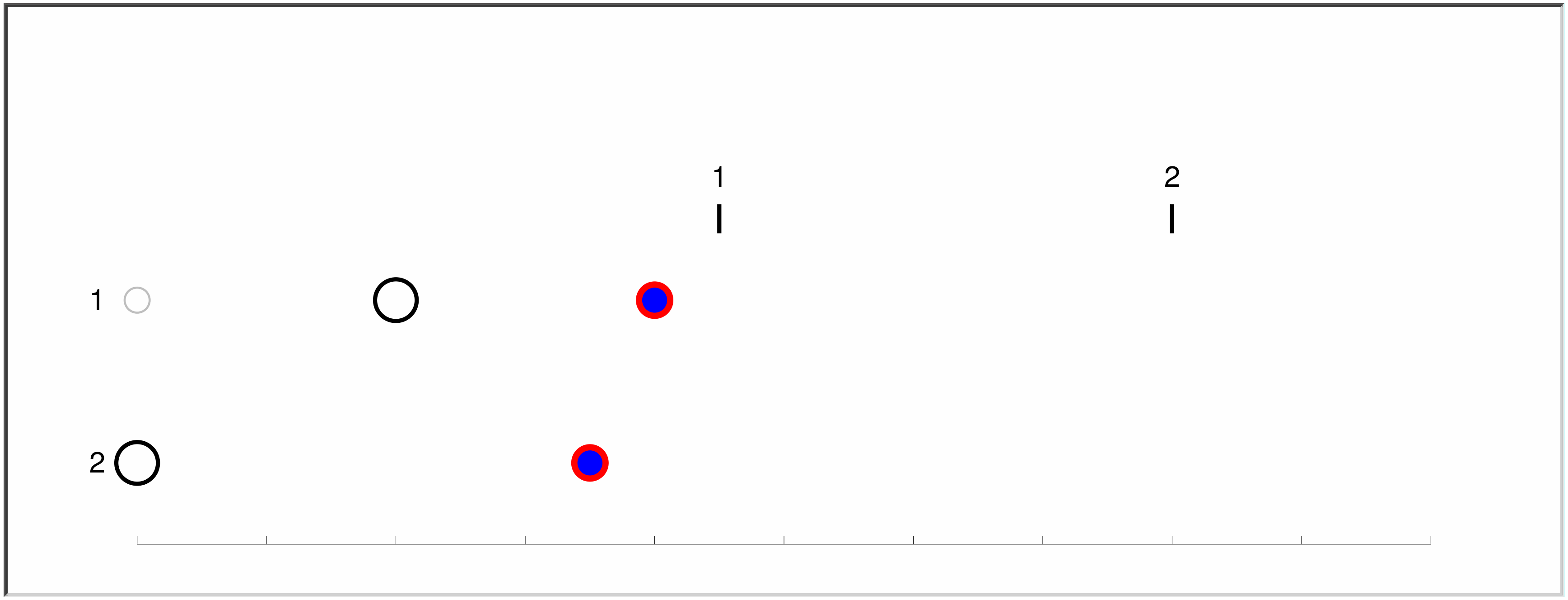
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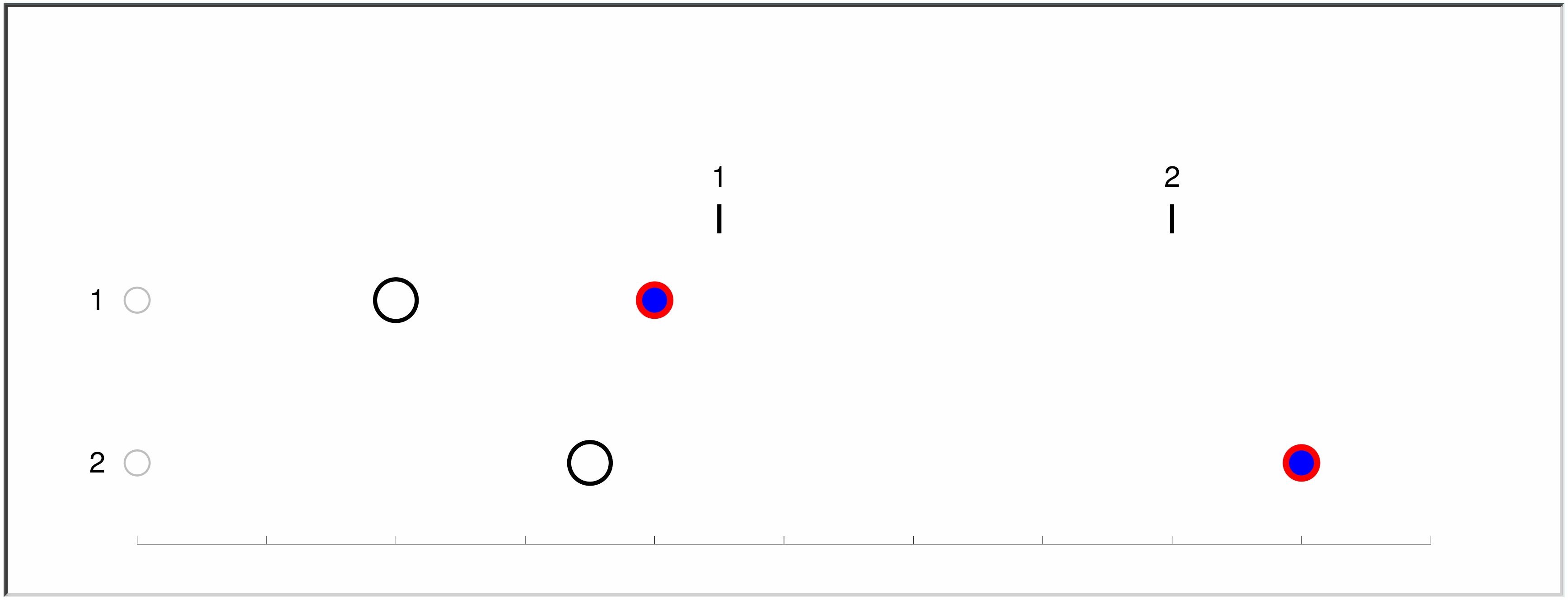
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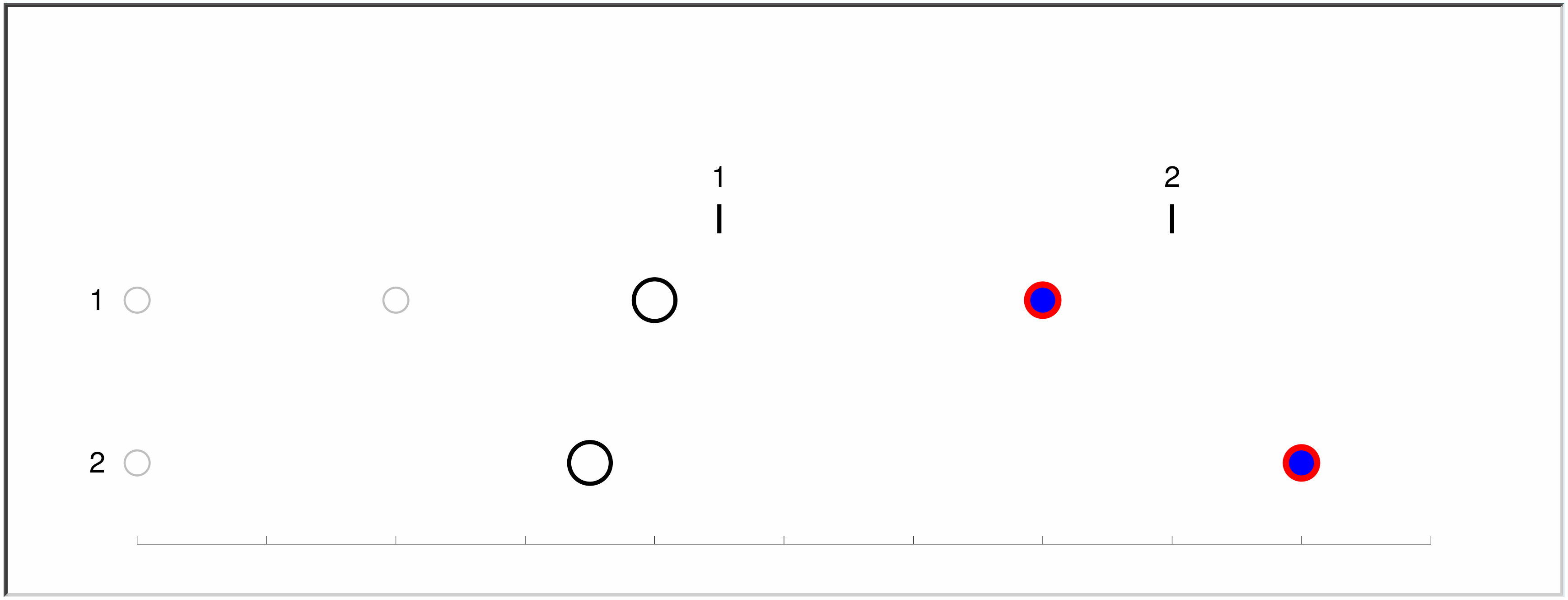
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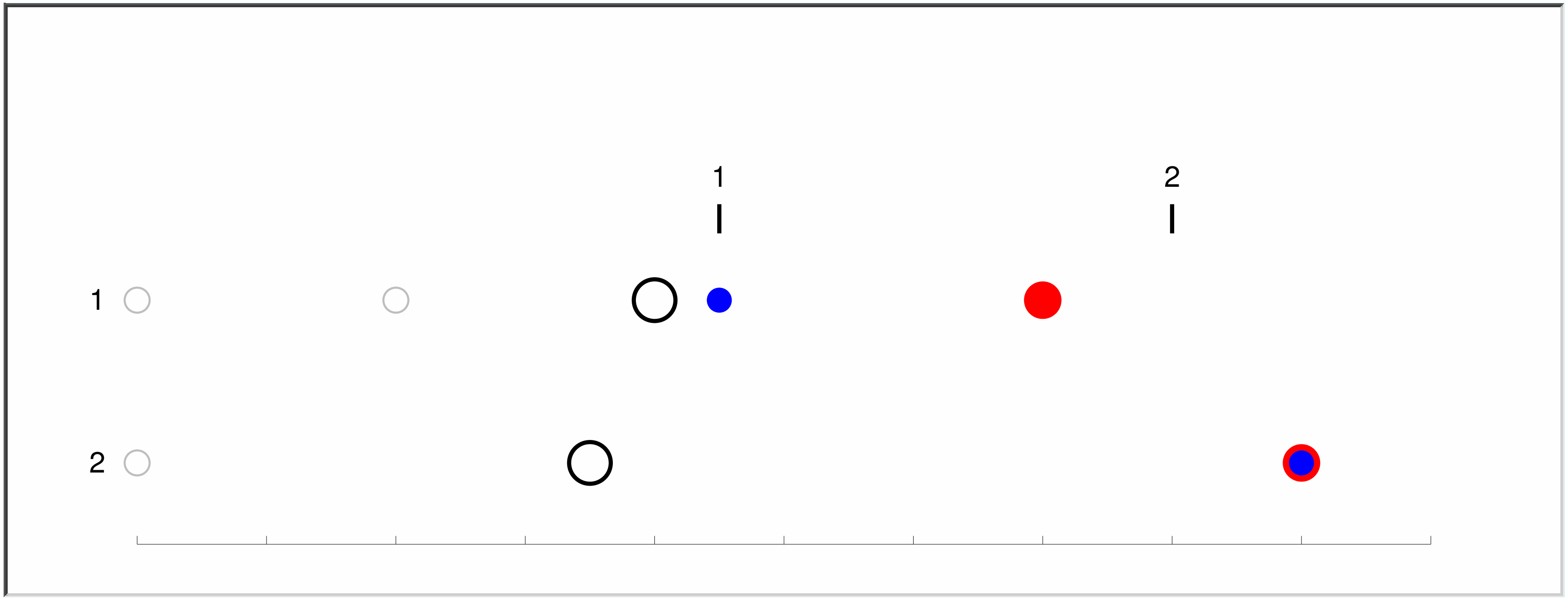
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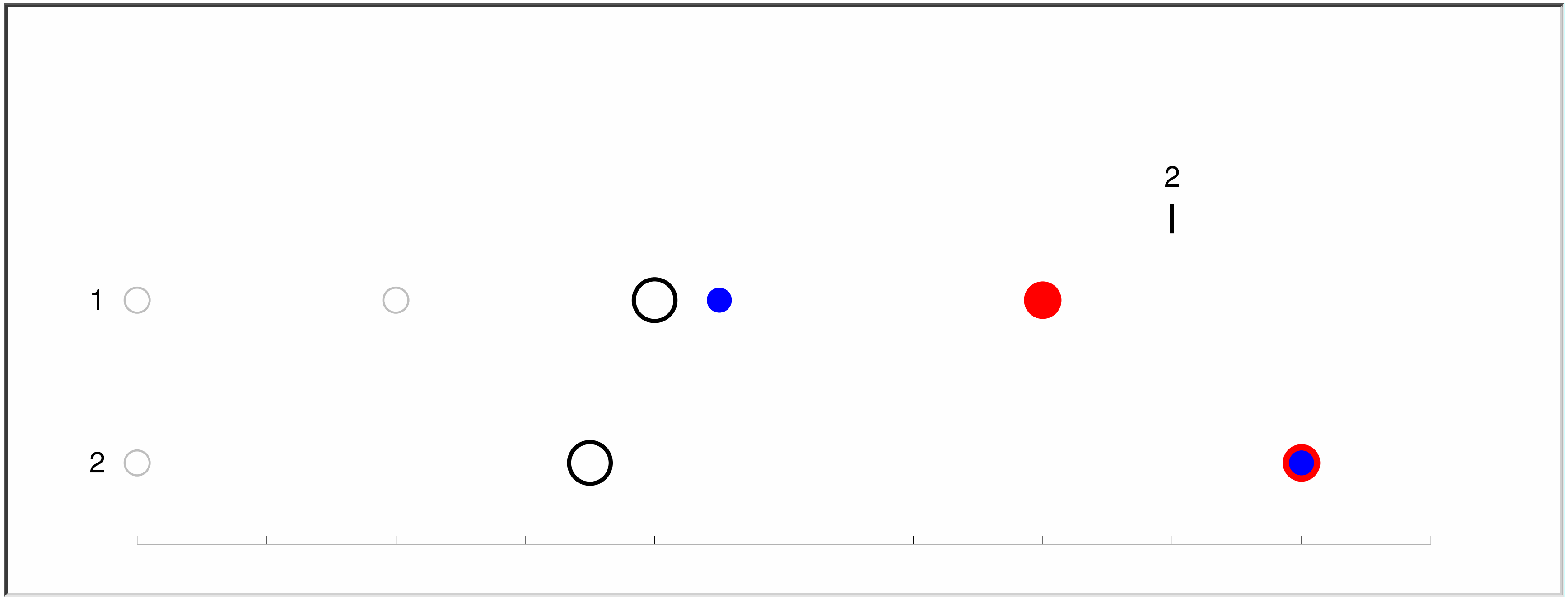
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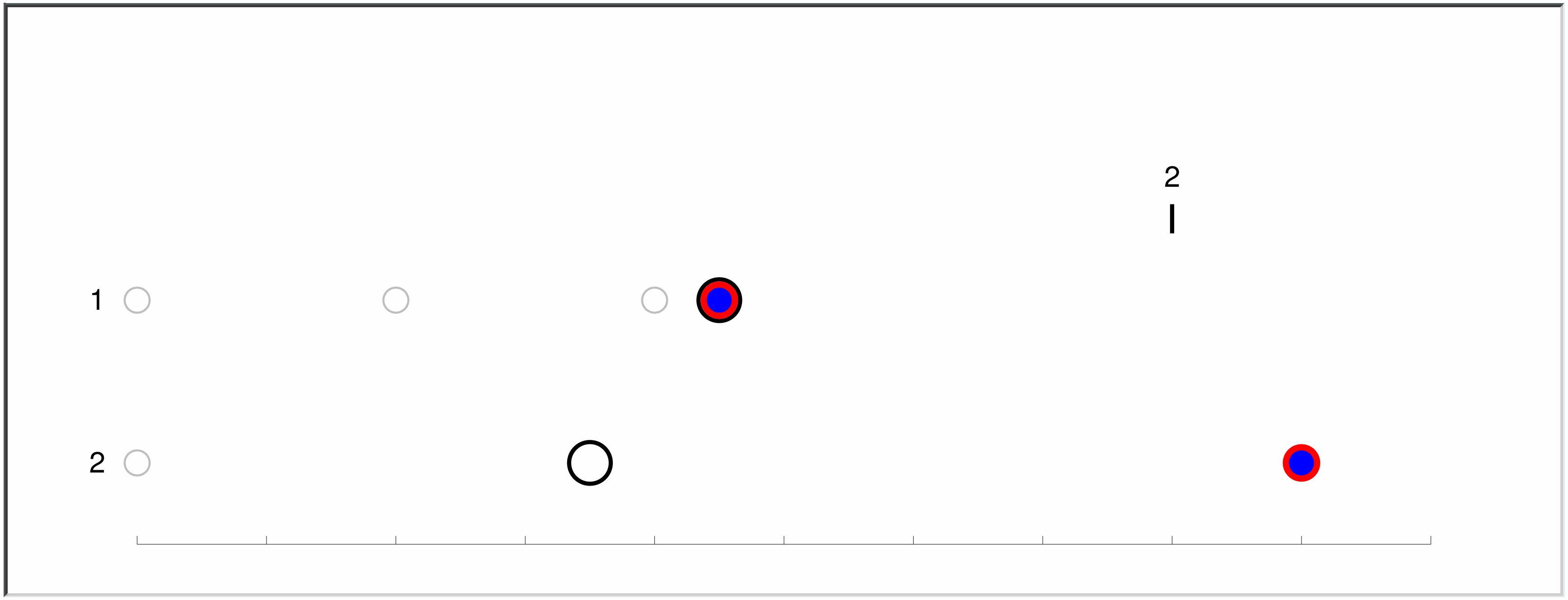

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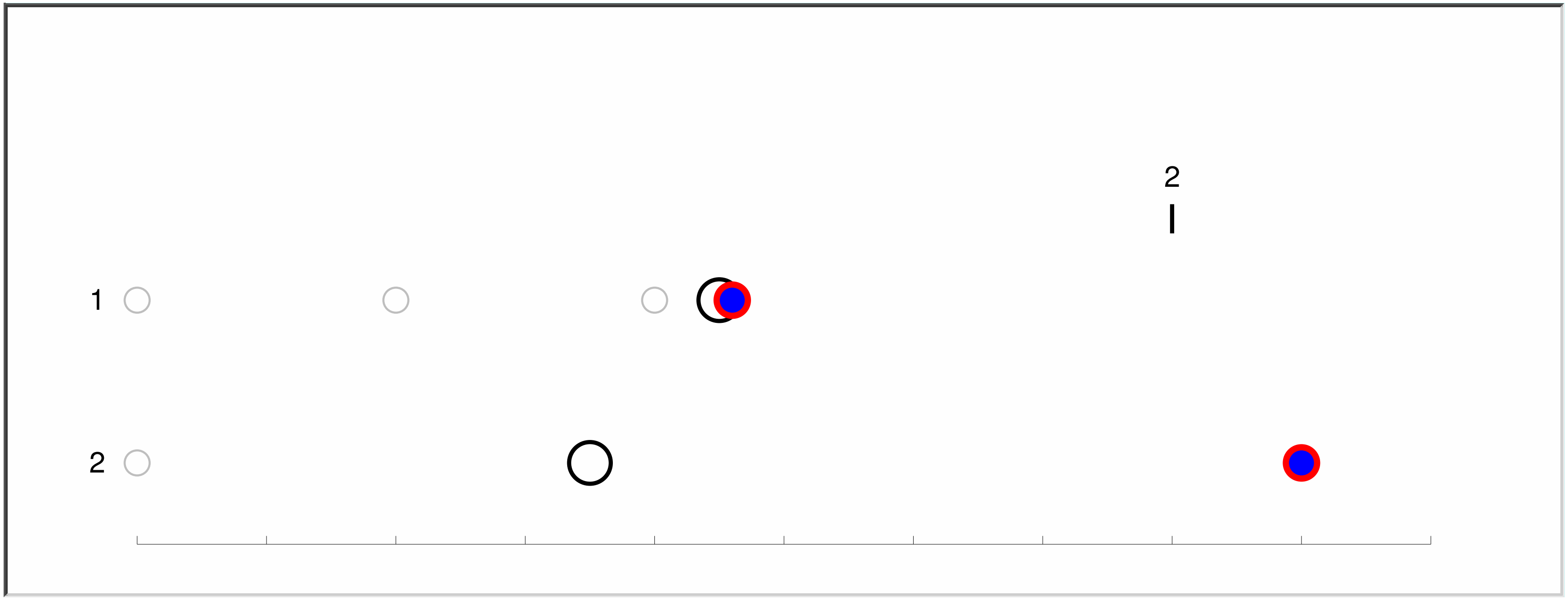
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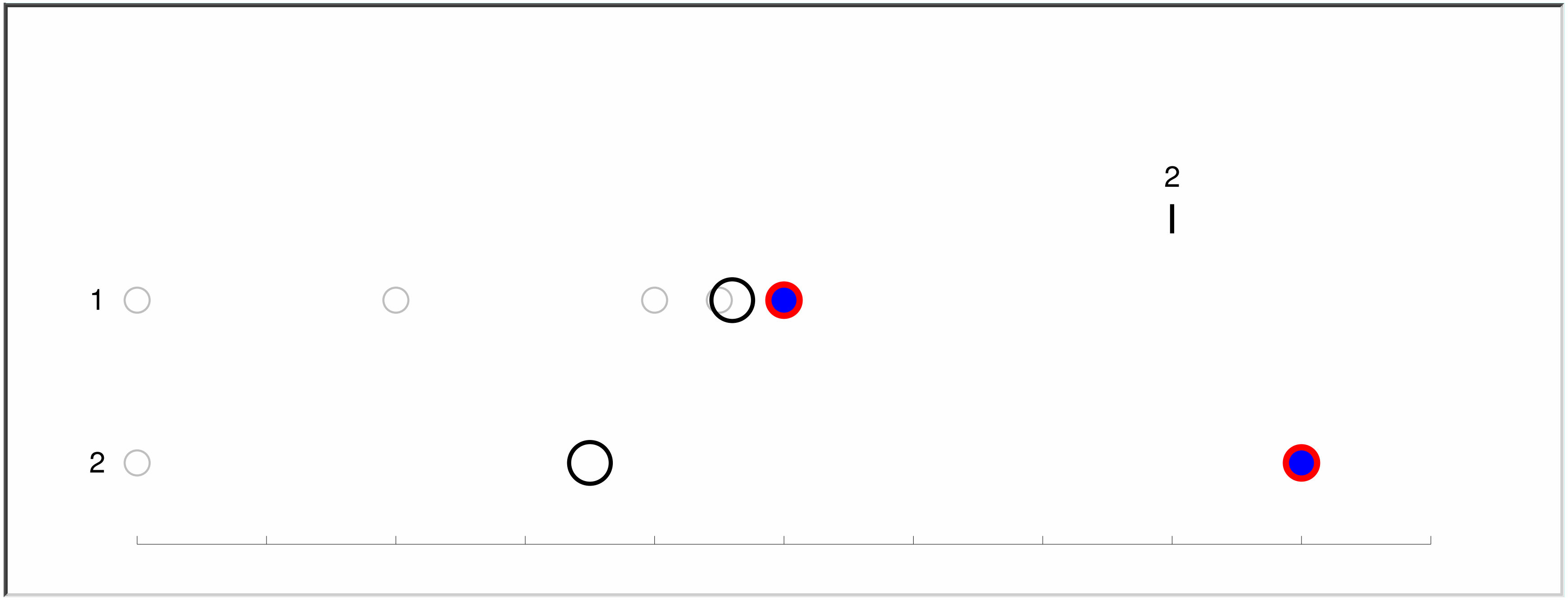
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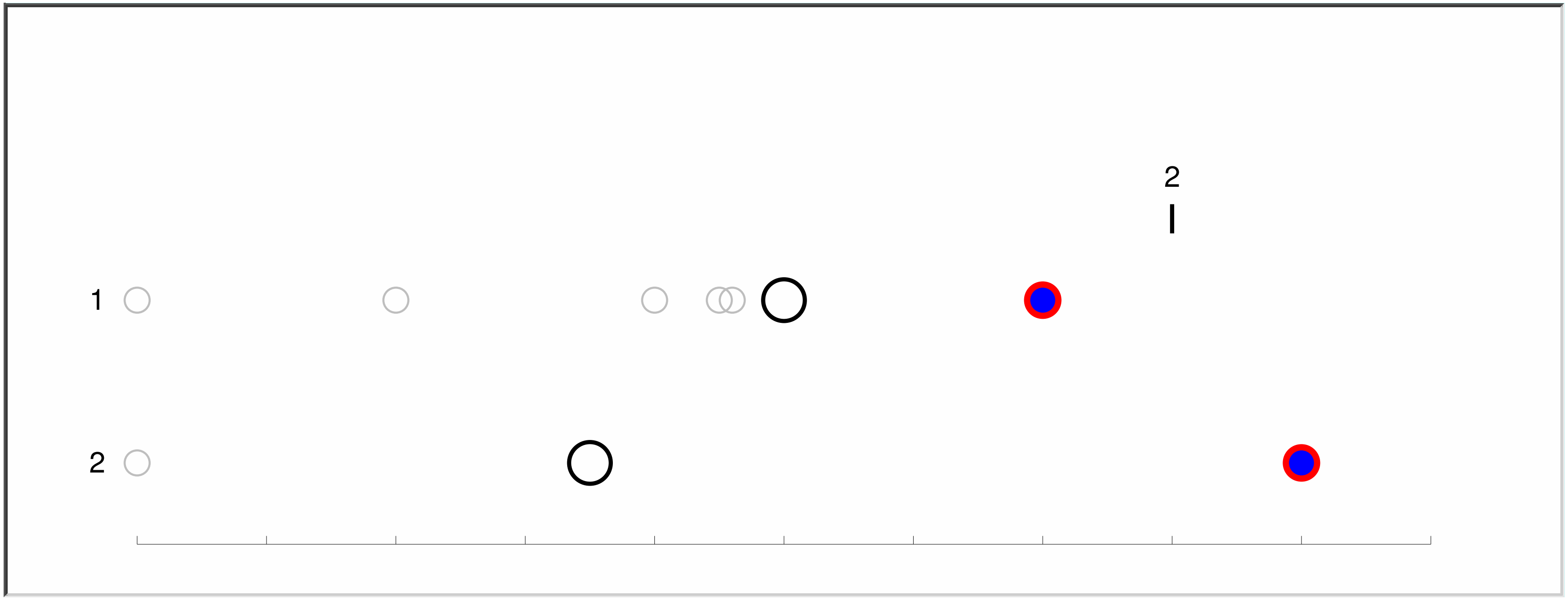
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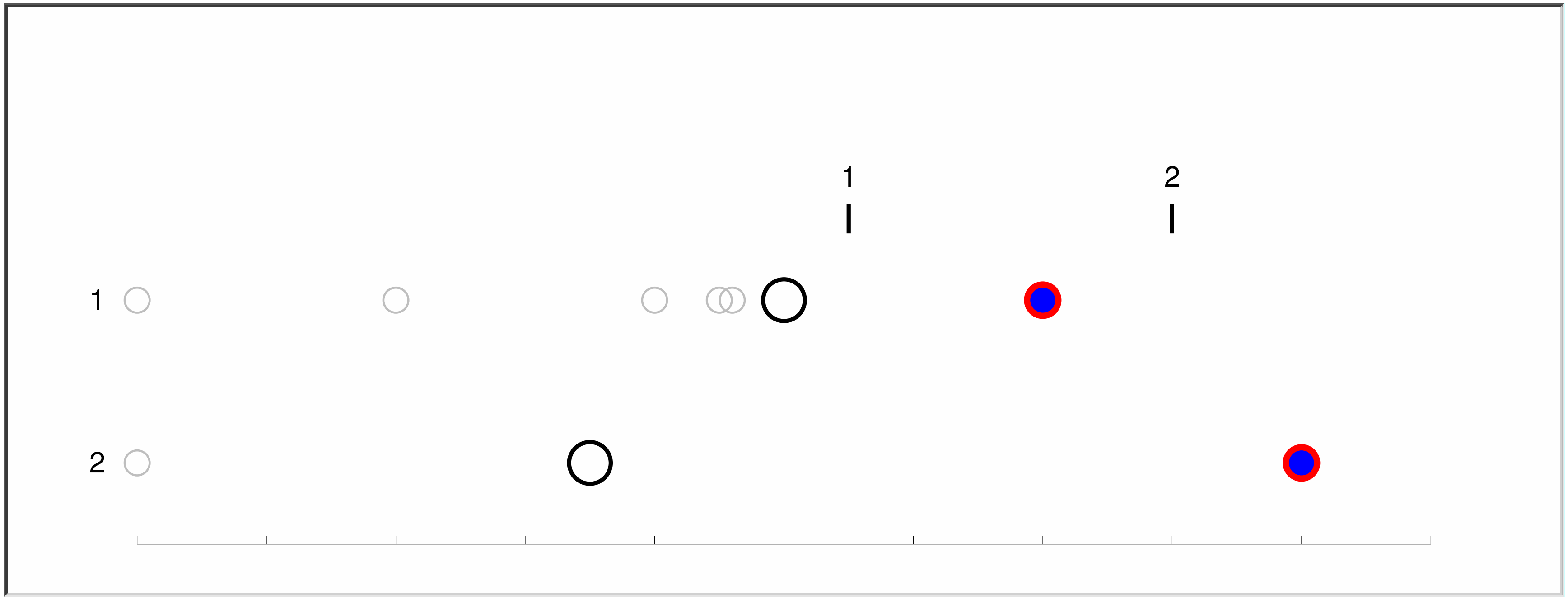
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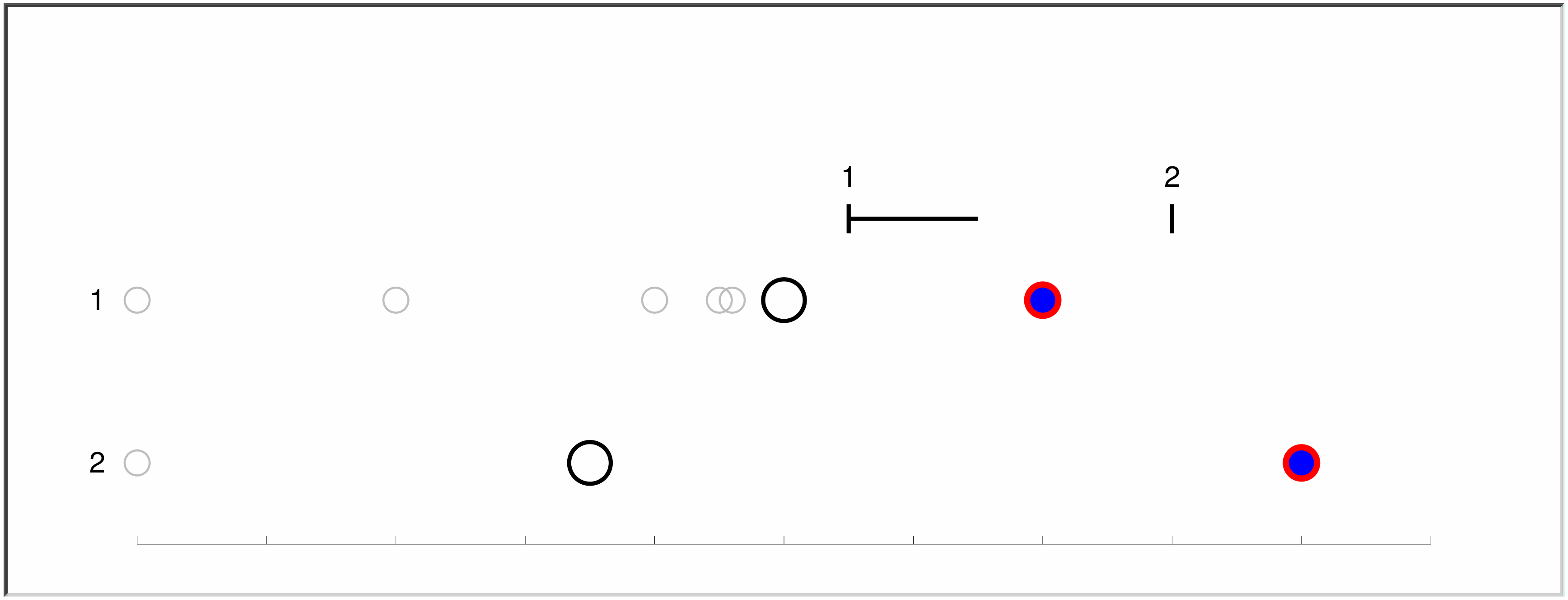
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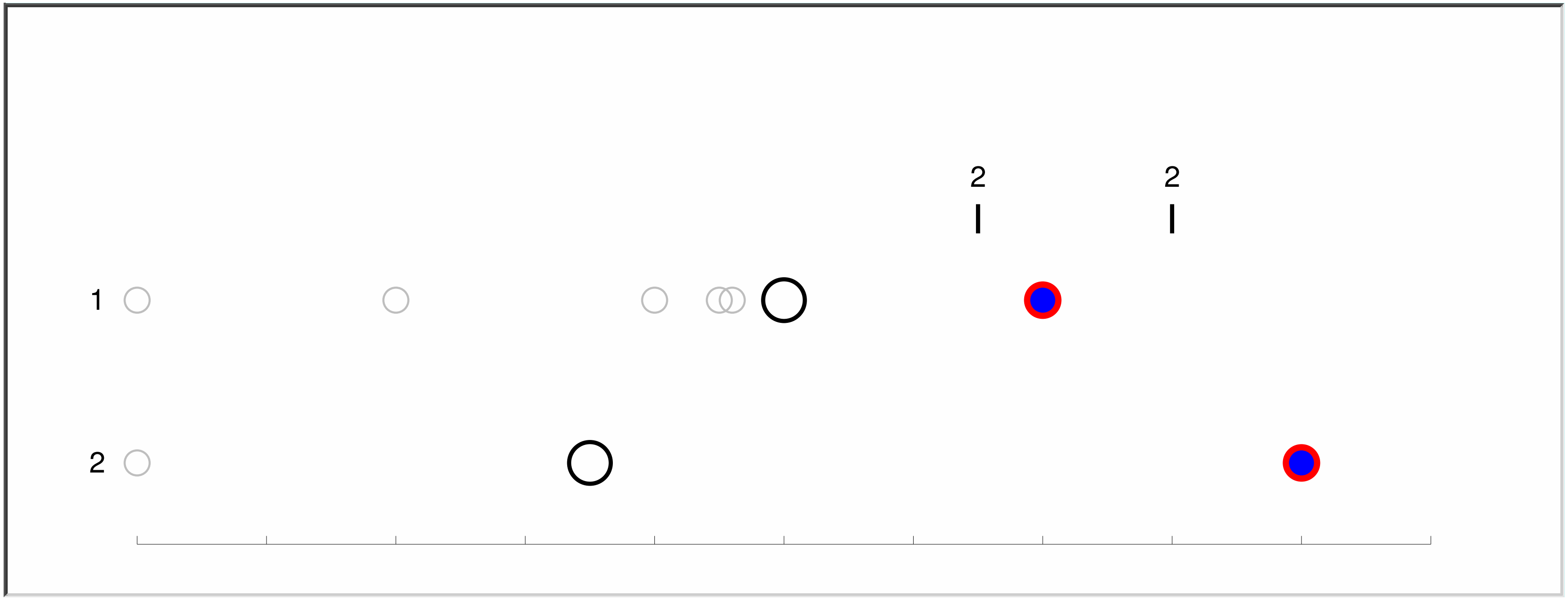

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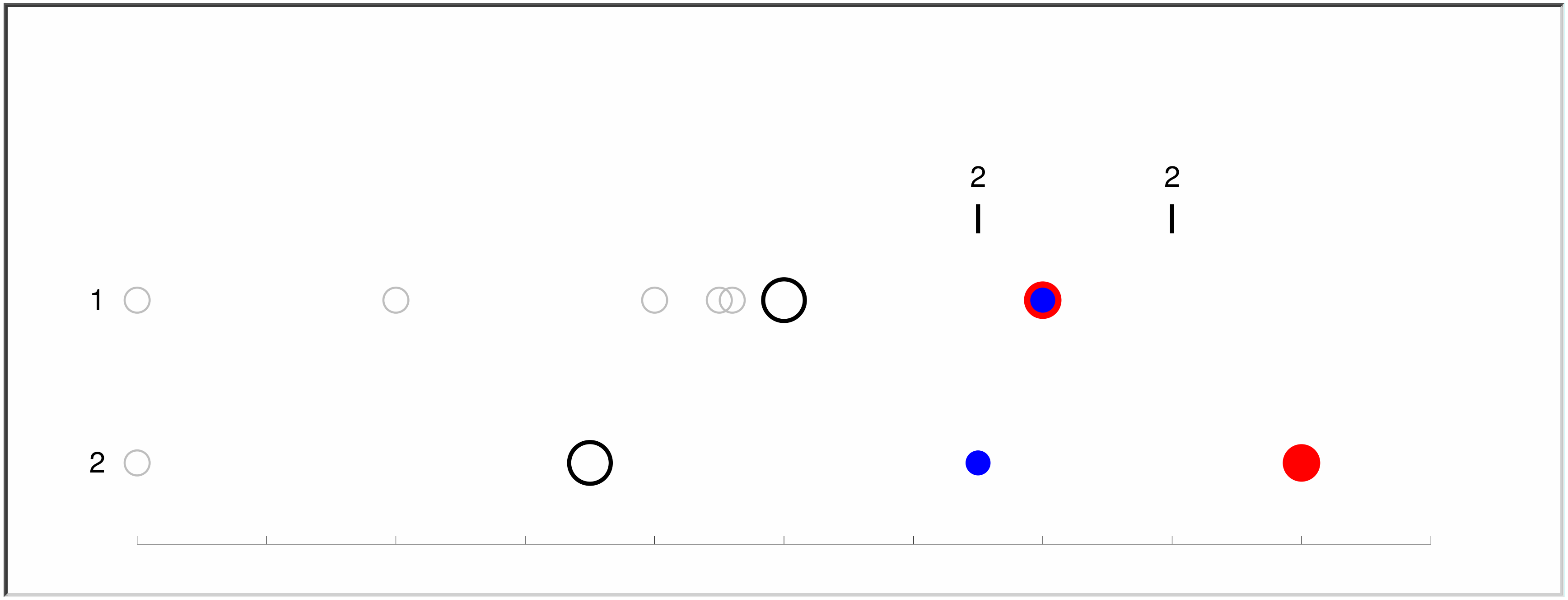

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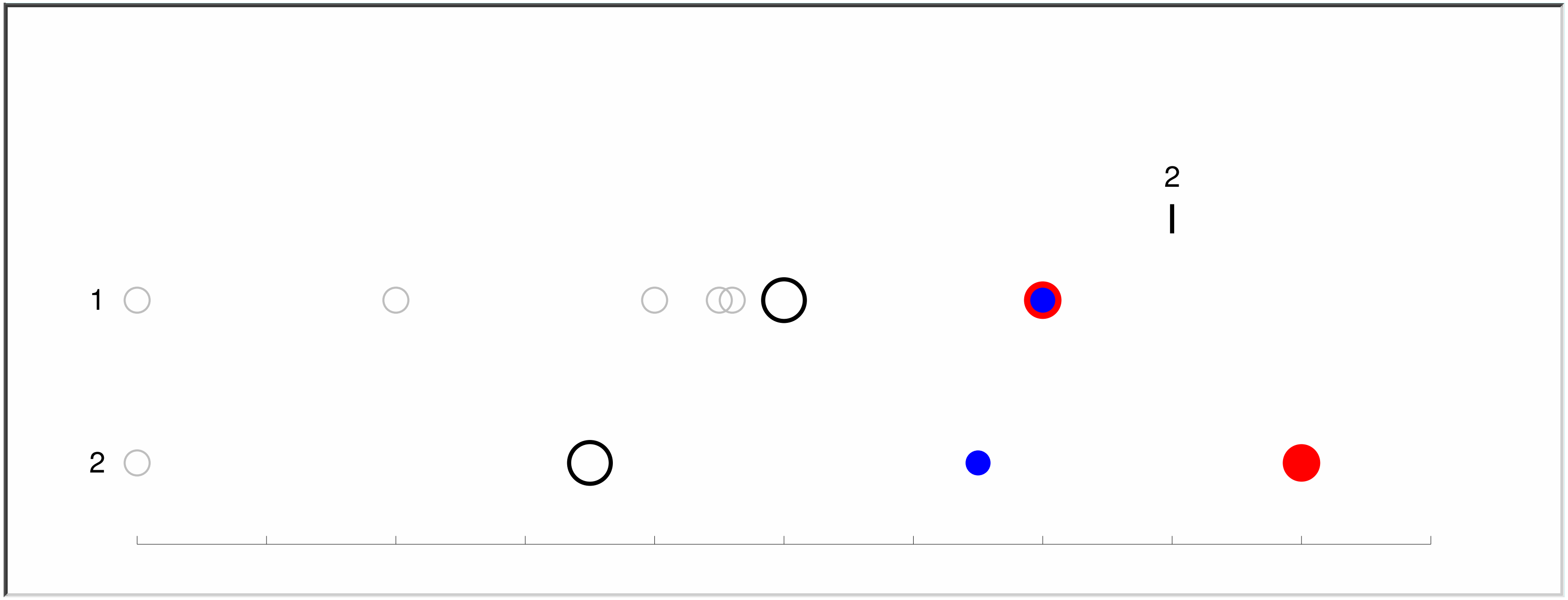
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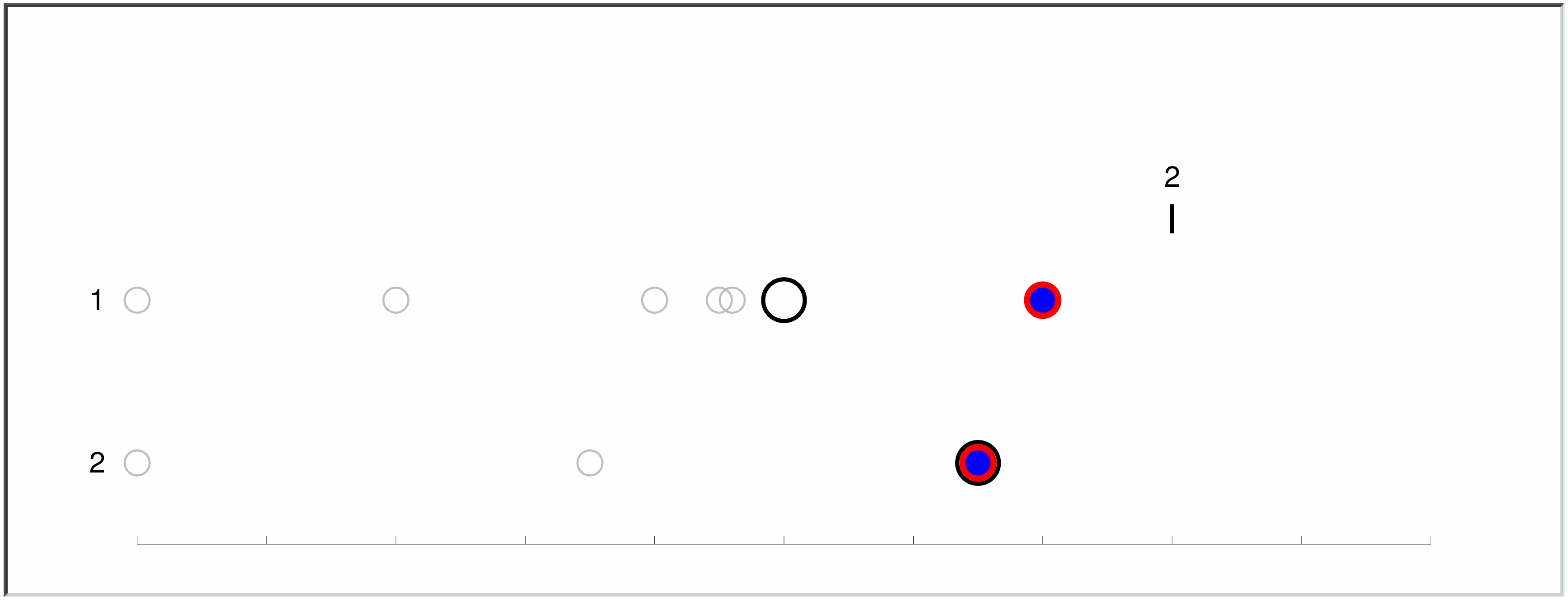
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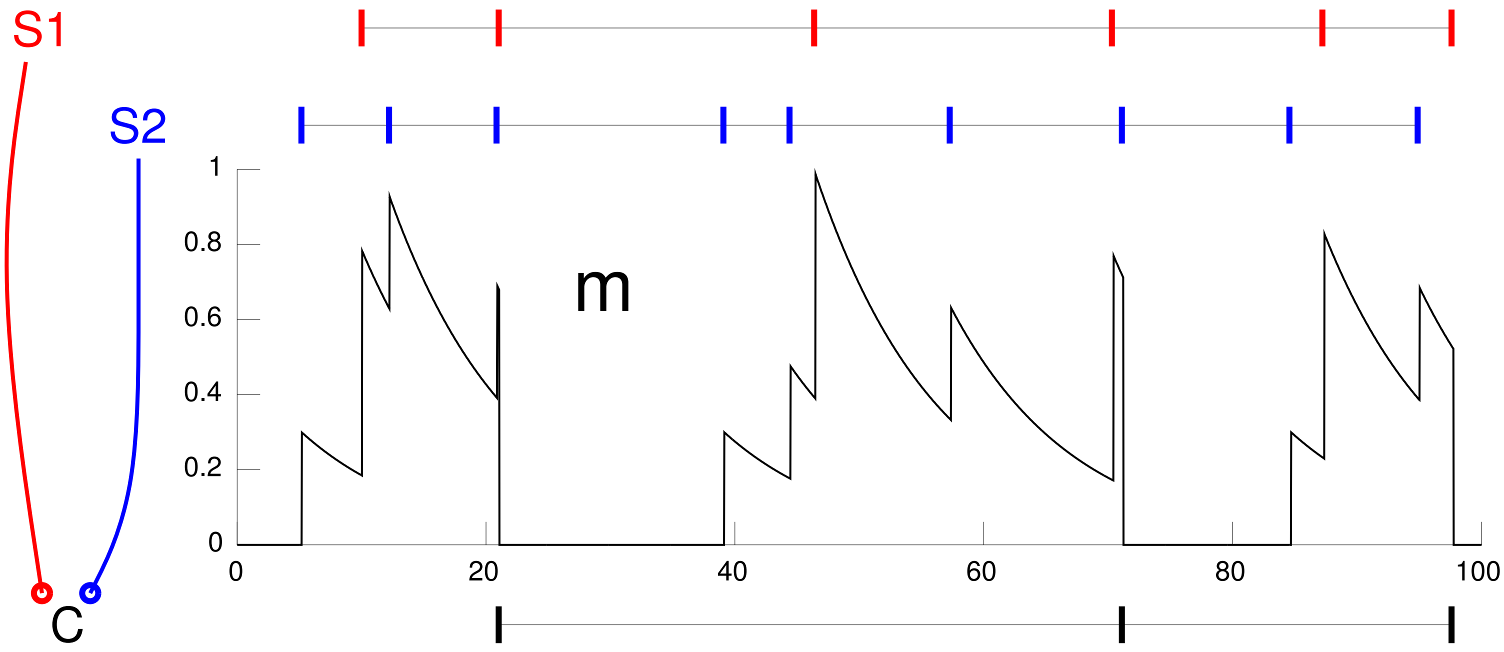
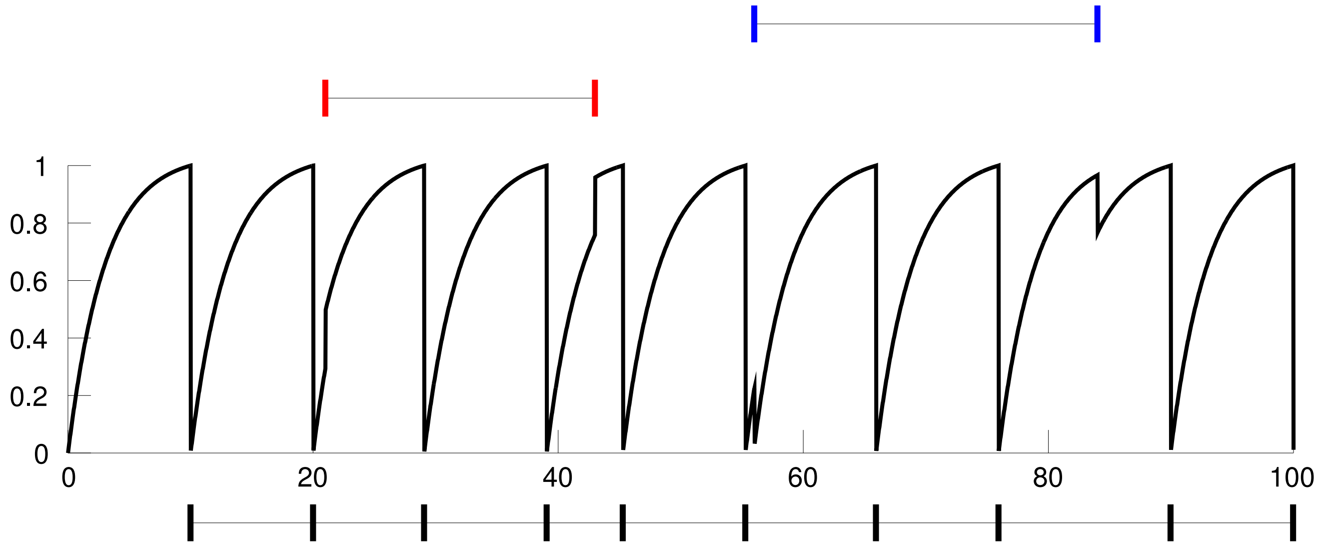


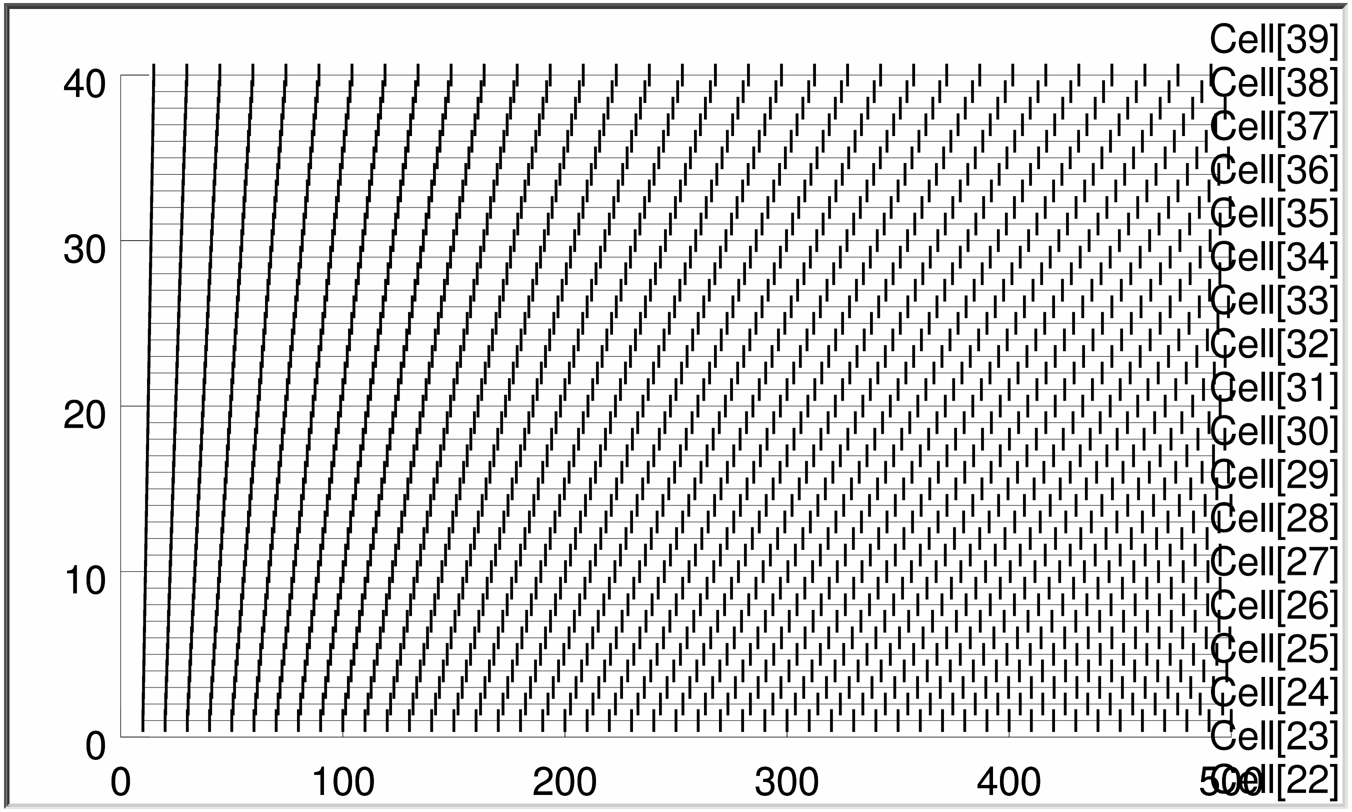

```
NEURON {
  ARTIFICIAL_CELL IntFire
  RANGE tau, m
}

...declarations...
```

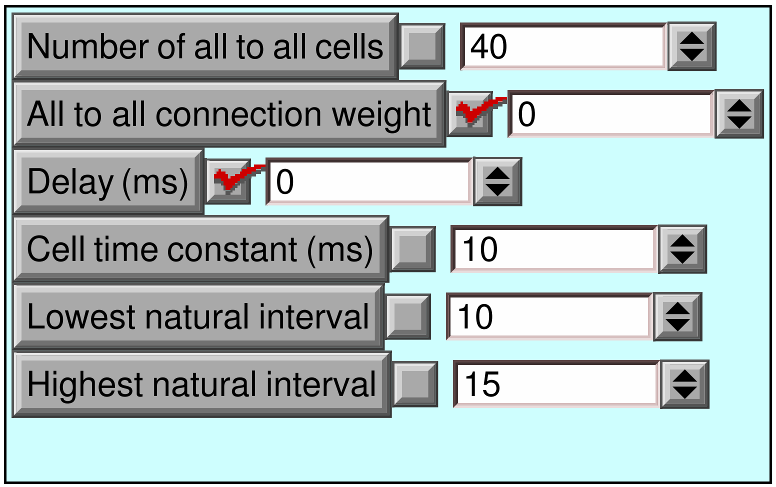
```
INITIAL { m = 0   t0 = t }

NET_RECEIVE (w) {
  m = m*exp(-(t - t0)/tau)
  t0 = t
  m = m + w
  if (m > 1) {
    net_event(t)
    m = 0
  }
}
```

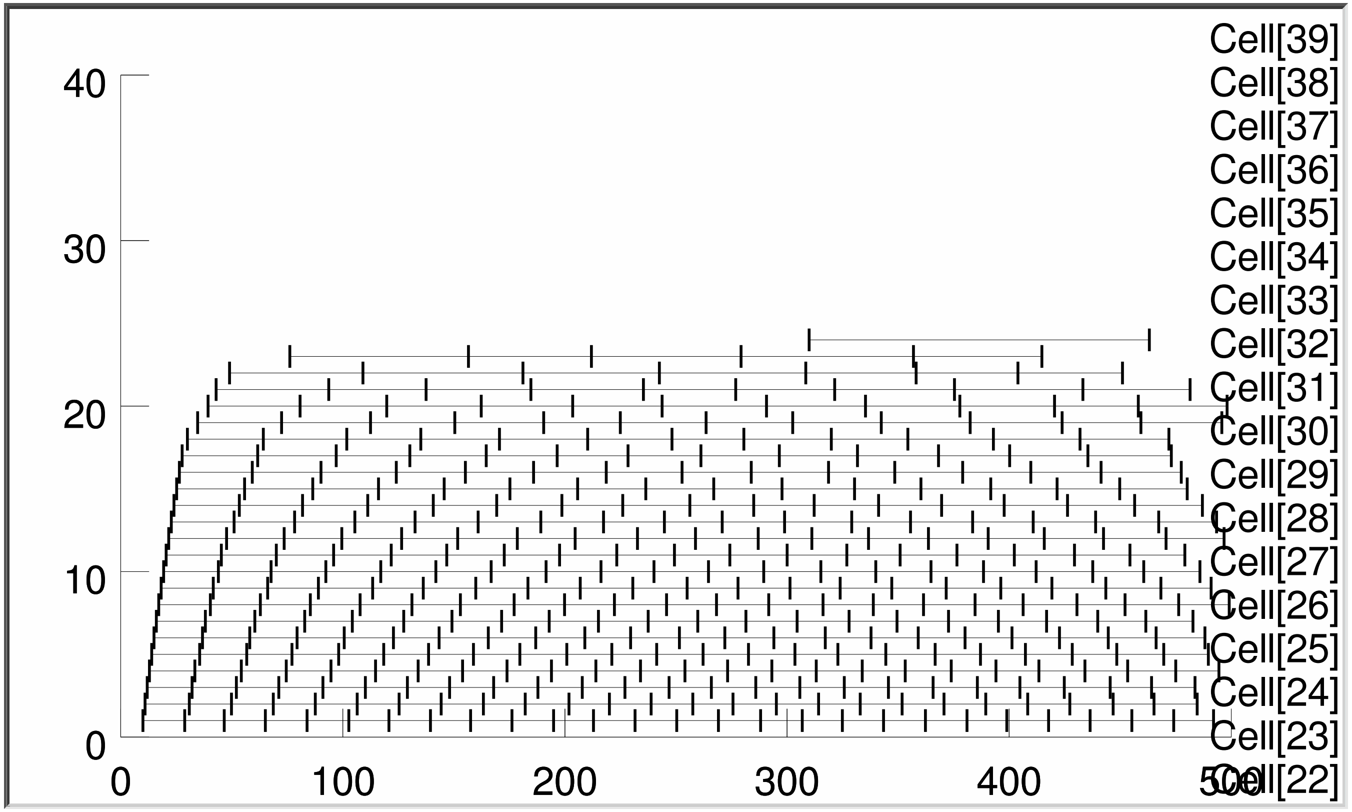


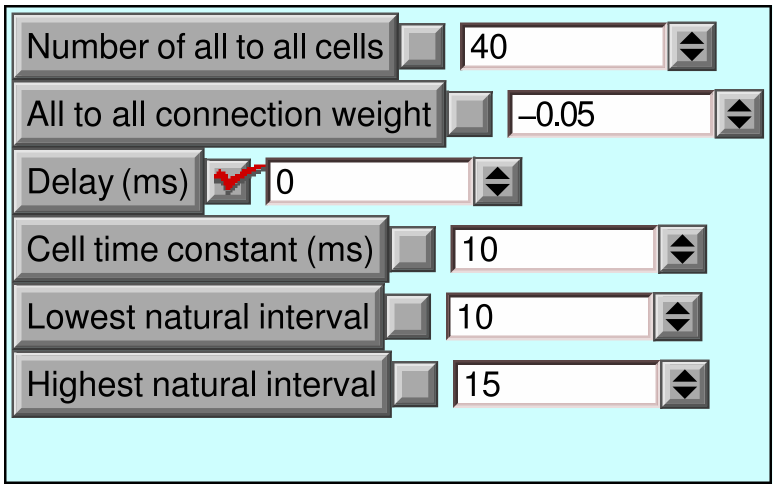

```
: dm/dt = (minf - m)/tau
: input event adds w to m
: when m = 1, or event
:  makes m >= 1, cell fires
: minf is calculated so
:  that the natural interval
:  between spikes is invl

INITIAL {
   minf = 1/(1 - exp(-invl/tau))
   m = 0
   t0 = t
   net_send(firetime(), 1)
}
```

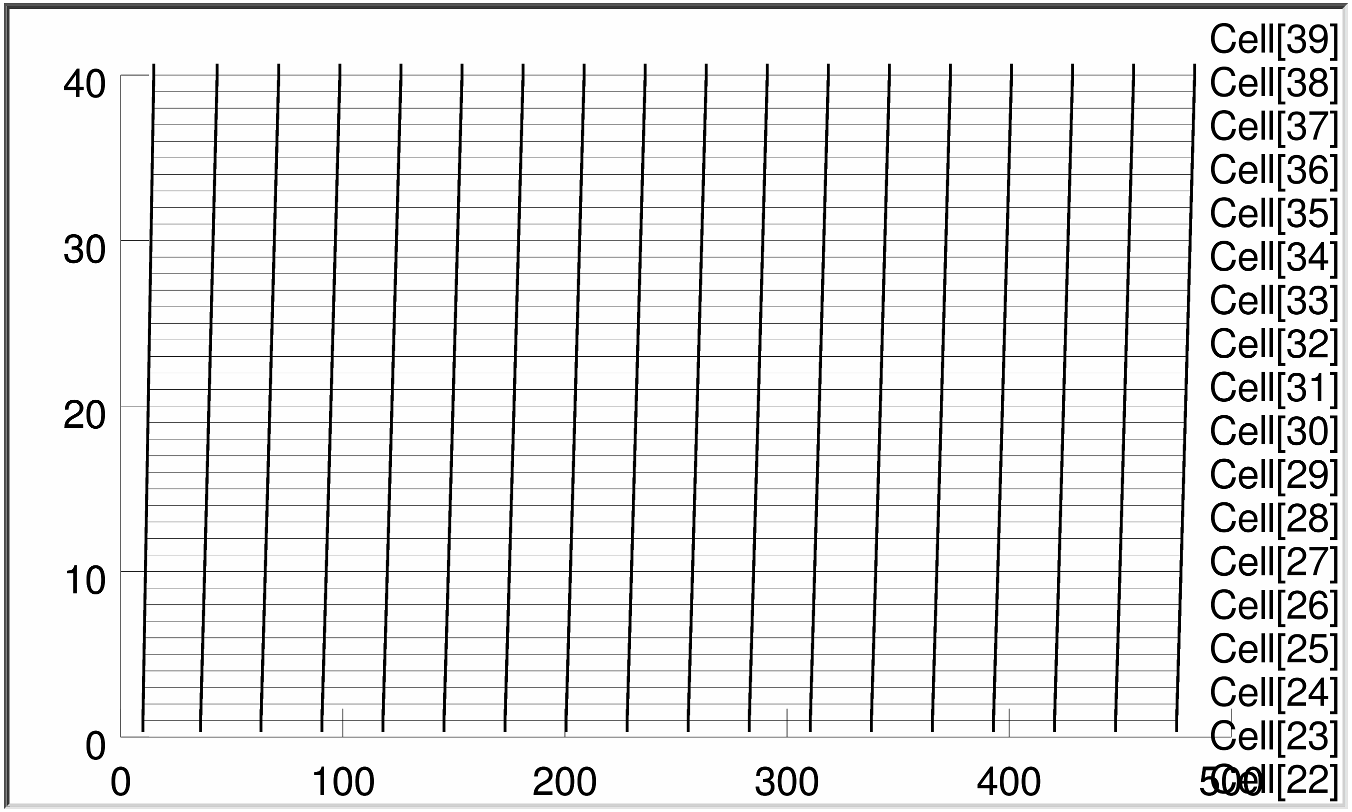
```
NET_RECEIVE (w) {
   m = minf + (m - minf)*exp(-(t - t0)/tau)
   t0 = t
   if (flag == 0) {
      m = m + w
      if (m > 1) {
         m = 0
         net_event(t)
      }
      net_move(t+firetime())
   }else{
      net_event(t)
      m = 0
      net_send(firetime(), 1)
   }
}

FUNCTION firetime() { : m < 1 < minf
   firetime = tau*log((minf-m)/(minf - 1))
}
```


Cell[39]
Cell[38]
Cell[37]
Cell[36]
Cell[35]
Cell[34]
Cell[33]
Cell[32]
Cell[31]
Cell[30]
Cell[29]
Cell[28]
Cell[27]
Cell[26]
Cell[25]
Cell[24]
Cell[23]
Cell[22]
40
30
20
10
0
0
100
200
300
400
500


Number of all to all cells
40
All to all connection weight
0
Delay (ms)
0
Cell time constant (ms)
10
Lowest natural interval
10
Highest natural interval
15


Cell[39]
Cell[38]
Cell[37]
Cell[36]
Cell[35]
Cell[34]
Cell[33]
Cell[32]
Cell[31]
Cell[30]
Cell[29]
Cell[28]
Cell[27]
Cell[26]
Cell[25]
Cell[24]
Cell[23]
Cell[22]
40
30
20
10
0
0
100
200
300
400
500


Number of all to all cells
40
All to all connection weight
–0.05
Delay (ms)
0
Cell time constant (ms)
10
Lowest natural interval
10
Highest natural interval
15


Cell[39]
Cell[38]
Cell[37]
Cell[36]
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400
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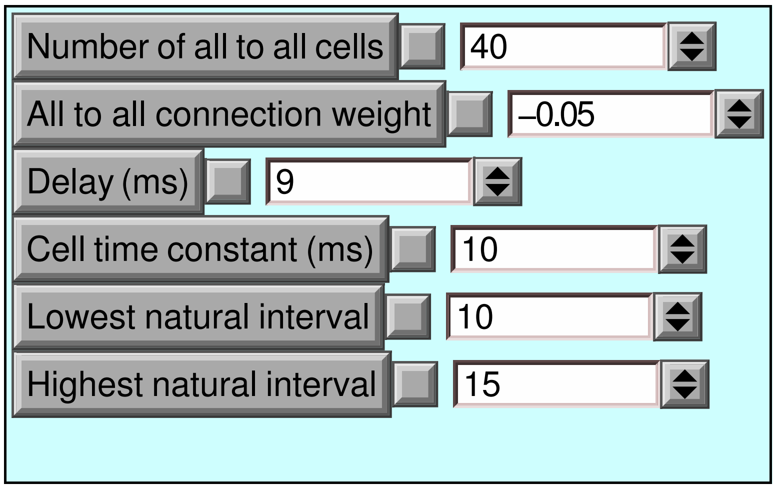
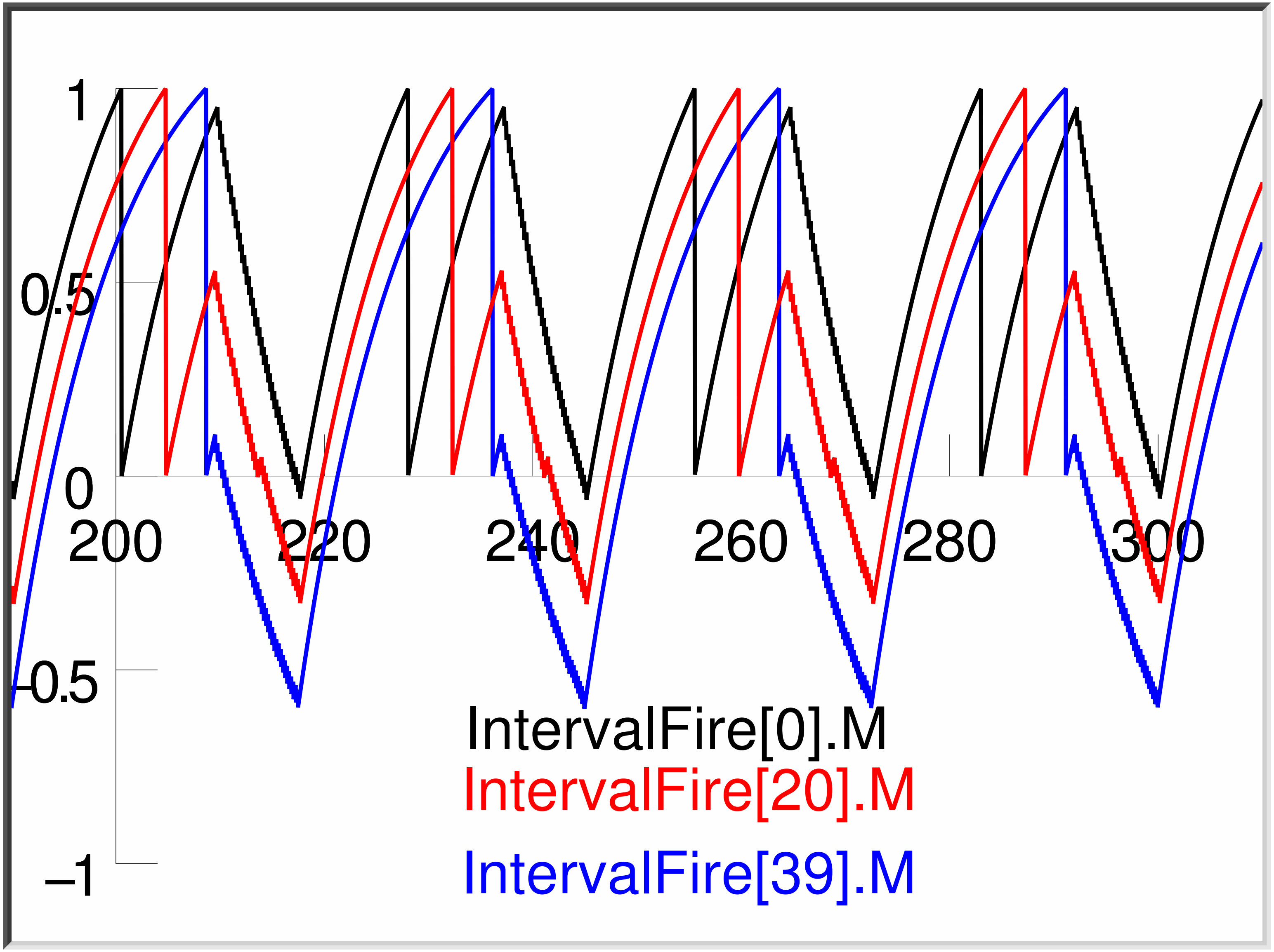

Number of all to all cells
40
All to all connection weight
–0.05
Delay (ms)
9
Cell time constant (ms)
10
Lowest natural interval
10
Highest natural interval
15


1
0.5
0
–0.5
–1
200
220
240
260
280
300
IntervalFire[0].M
IntervalFire[20].M
IntervalFire[39].M

The NEURON Book

Ted Carnevale
and
Michael Hines