Init

```
Needs["CCompilerDriver`"]
```

```
SetDirectory[NotebookDirectory[]];
```

```
libraryPath = CreateLibrary[
    {"cfiles/link.c",
     "cfiles/boids.c"},
    "boids",
    "IncludeDirectories" → {Directory[] <> "/cfiles"}];
Print[libraryPath]
```

```
/Users/christopher/Library/Mathematica/SystemFiles/LibraryResources/MacOSX-x86-64/boids.
  dylib
```

```
runBoids = LibraryFunctionLoad[libraryPath, "runBoids", {Integer(*step count*),
    Integer(*steps to return count*), {Real, 2}(*initial positions*),
    {Real, 2}(*initial velocities*), {Real, 2}(*parameters*)}, {Real, 3}]
```

```
LibraryFunction[ Function name: runBoids
                 Argument count: 5 ]
```

Without Predators

```
initPos = RandomReal[{-1, 1}, {100, 1}];
initVel = RandomReal[{-1, 1}, {100, 1}];
parameters =
  Table[{10(*alignment*), 1(*seperation*), 1(*cohesion*), 0(*species*),
    1(*mass*), 0.3(*visibility radius*), 0.01(*max velocity*), 0.001
    (*max acceleration*), 0.025(*seperation radius*), 1.0(*fear*),
    0(*predator frames*), 10(*frames to death*)}, {100}];
```

```
initPos = RandomReal[{-1, 1}, {1000, 2}];
initVel = RandomReal[{-1, 1}, {1000, 2}];
parameters =
  Table[{10(*alignment*), 1(*seperation*), 1(*cohesion*), 0(*species*),
    1(*mass*), 0.3(*visibility radius*), 0.01(*max velocity*), 0.001
    (*max acceleration*), 0.025(*seperation radius*), 1.0(*fear*),
    0(*predator frames*), 10(*frames to death*)}, {1000}];
```

```
initPos = RandomReal[{-1, 1}, {1000, 2}];
initVel = RandomReal[{-1, 1}, {1000, 2}];
parameters =
  Table[{10(*alignment*), 1(*seperation*), 10(*cohesion*), 0(*species*),
    1(*mass*), 0.3(*visibility radius*), 0.01(*max velocity*), 0.001
    (*max acceleration*), 0.025(*seperation radius*), 1.0(*fear*),
    0(*predator frames*), 10(*frames to death*)}, {1000}];

steps = runBoids[1000, 1000, initPos, initVel, parameters];

AbsoluteTiming[runBoids[1000, 2, initPos, initVel, parameters];]
```

```
{0.089834, Null}
```

```
0.079085` * (100^3) / 60 / 60 / 4
```

```
5.49201
```

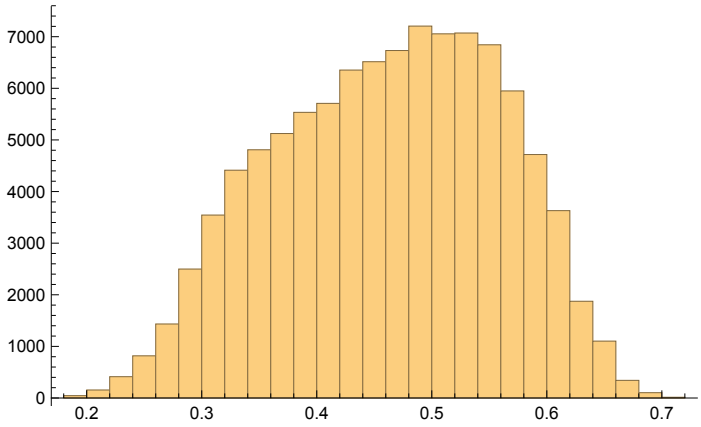
```
7.34016`
```

```
10^3 * 10 / 60 / 60 // N
```

```
2.77778
```

```
10.706806`
```

```
center = Mean[Catenate[steps]];
distances = EuclideanDistance[center, #] & /@ Catenate[steps];

Histogram[distances]
```



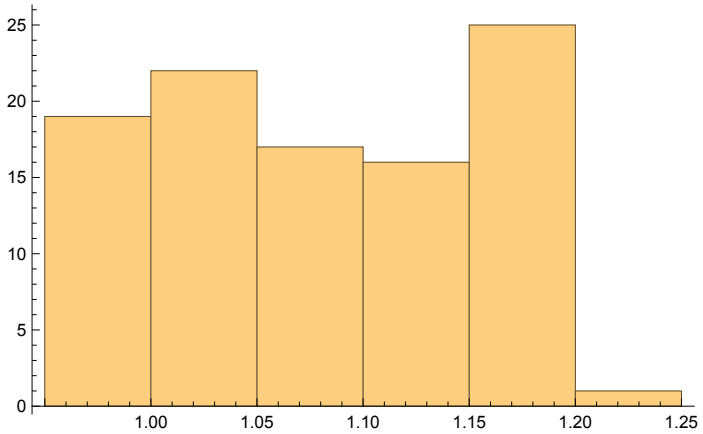

```
Mean[distances]
```

```
0.461488
```

```
StandardDeviation[distances]
```

```
0.097804
```

```
Histogram[Norm /@ (Subtract @@ Reverse@steps[[-2 ;;]])]
```

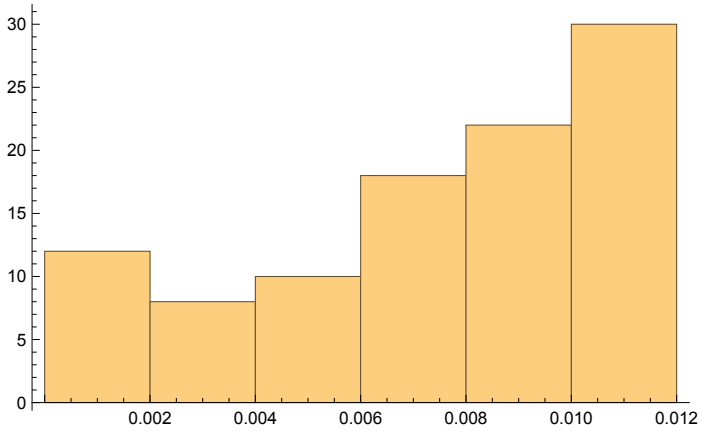


A reasonable measure of something:

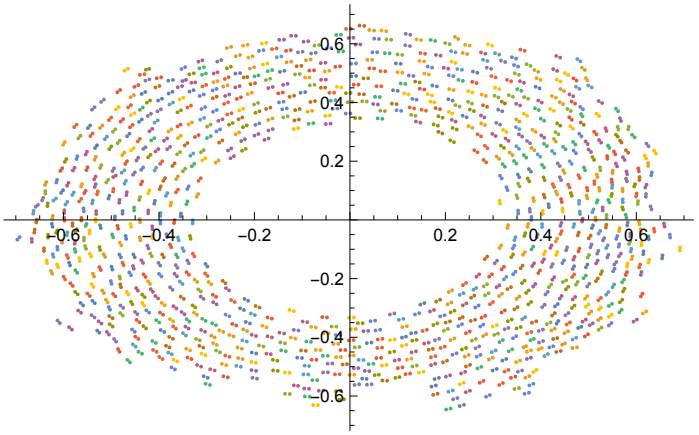
```
Mean[Norm /@ (Subtract @@@ steps[[All, -2 ;;]])]
```

```
0.00566809
```

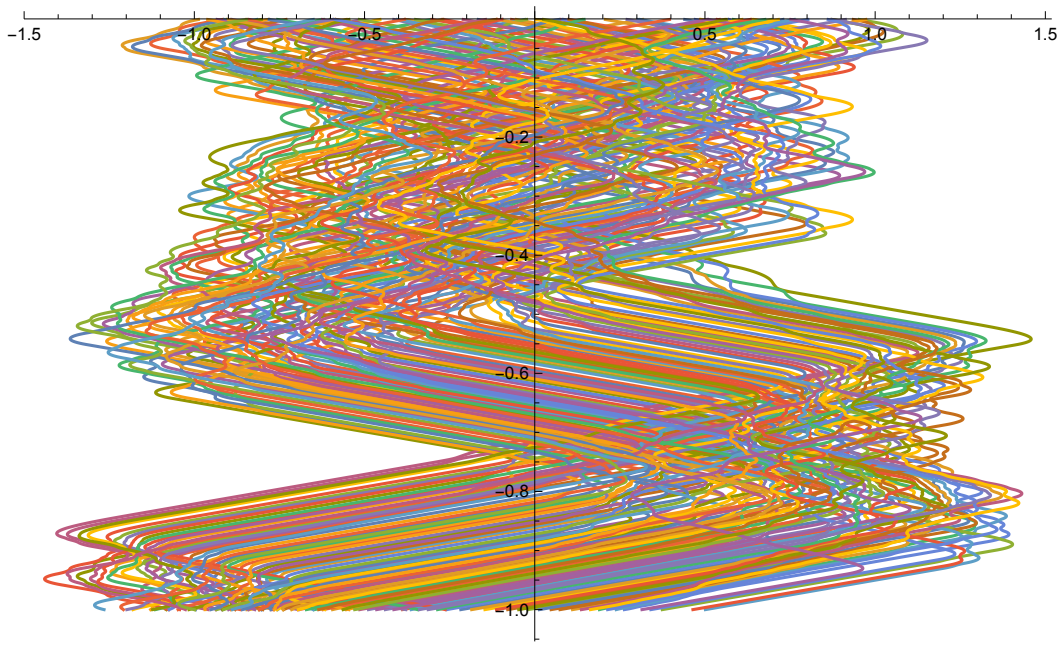
```
Histogram[Norm /@ (Subtract @@@ steps[[All, -2 ;;]])]
```




```
ListPlot@steps[[All, -2 ;;]]
```



```
ListLinePlot[MapIndexed[{#1, -First[#2] / 1000} &, #] & /@ steps[[All, All, 1]],
 PlotRange → {Automatic, All}]
```

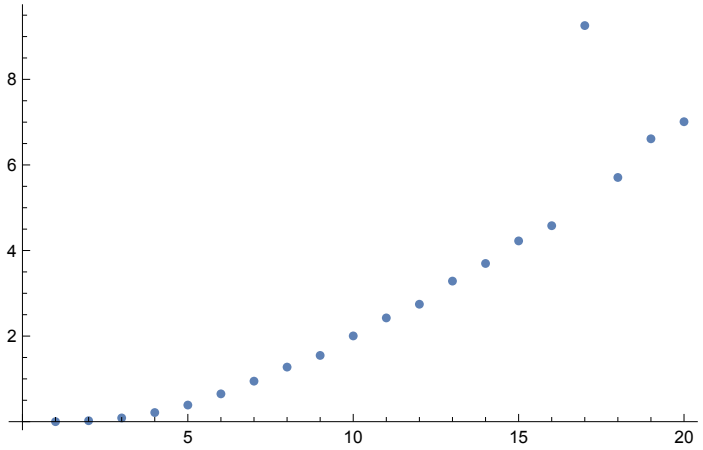


Phase Diagram

```
times = Table[Module[{initPos, initVel, parameters},
    initPos = RandomReal[{-1, 1}, {n, 2}];
    initVel = RandomReal[{-1, 1}, {n, 2}];
    parameters =
     Table[{10(*alignment*), 1(*seperation*), 1(*cohesion*), 0(*species*),
       1(*mass*), 0.3(*visibility radius*), 0.01(*max velocity*),
       0.001(*max acceleration*), 0.025(*seperation radius*), 1.0
       (*fear*), 0(*predator frames*), 10(*frames to death*)}, {n}];
    AbsoluteTiming[runBoids[1000, 2, initPos, initVel, parameters]][[1]]
   ], {n, 1, 1000, 50}]
```

```
{0.000273, 0.022402, 0.086847, 0.212882, 0.388209, 0.649892,
 0.946567, 1.27527, 1.54806, 2.00375, 2.4247, 2.74454, 3.28513,
 3.69716, 4.22439, 4.57997, 9.25714, 5.70732, 6.61105, 7.00996}
```

```
ListPlot[times]
```




```
if = Interpolation[Transpose[{Range[1, 1000, 50], times}]]
```

InterpolatingFunction[Domain: {{1., 951.}} Output: scalar]

```
100^3 * if[200] / 3 / 60 / 60
```

36.6844

```
Dimensions[steps2]
```

{200, 1000, 2}

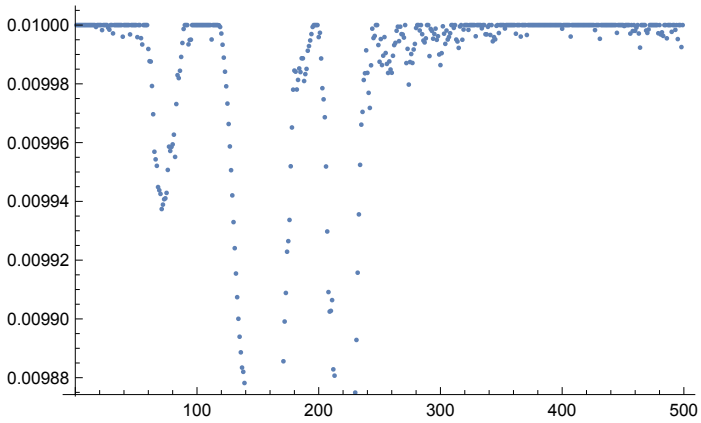
```
Transpose[steps2][[-500 ;;]]
```

{{{-1.05837, -0.789296}, {-0.24979, -0.0763523}, {2.79794, -0.251807},
{1.59536, 0.474895}, {-0.668717, 0.474544}, {3.319, -0.526554},
{-0.817533, -0.88365}, {-0.0897784, 0.336451}, ··· 184 ···,
{1.59199, 0.0797473}, {3.33536, -0.48146}, {-0.565913, 0.0760649},
{-1.1367, -0.881877}, {3.29441, -0.380596}, {-0.932509, -0.784458},
{3.28443, -0.501919}, {1.31412, 0.396489}}, ··· 498 ···, {··· 1 ···}}

large output | show less | show more | show all | set size limit...

```
{Mean[#], Median[#], StandardDeviation[#]} & /@
 Map[Norm, Subtract @@@ Partition[Transpose[steps2][[-500 ;;]], 2, 1], {2}]
```

```
ListPlot[
 Mean /@ Map[Norm, Subtract @@@ Partition[Transpose[steps2][[-500 ;;]], 2, 1], {2}]]
```




```
Dimensions[Subtract @@@ Partition[Transpose[steps2][[-500 ;;]], 2, 1]]
```

```
{499, 200, 2}
```

```
Dimensions[steps2[[All, -500 ;;]]]
```

```
{200, 500, 2}
```

Space3:

```
LaunchKernels[6]
```

```
{KernelObject[1, local], KernelObject[2, local], KernelObject[3, local],
 KernelObject[4, local], KernelObject[5, local], KernelObject[6, local]}
```

```
Now + 16.3764245` min
```

Thu 21 Sep 2017 11:28:20 GMT−7.

```
space3 = ParallelTable[Module[{initPos, initVel, parameters, steps, norms, n, s},
    s = 1;
    n = 200;
    initPos = RandomReal[{-1, 1}, {n, 2}];
    initVel = RandomReal[{-1, 1}, {n, 2}];
    parameters =
     Table[{a(*alignment*), s(*seperation*), c(*cohesion*), 0(*species*),
       1(*mass*), 0.3(*visibility radius*), 0.01(*max velocity*),
       0.001(*max acceleration*), 0.025(*seperation radius*), 1.0
       (*fear*), 0(*predator frames*), 10(*frames to death*)}, {n}];
    steps = runBoids[1000, 500, initPos, initVel, parameters];
    norms = Map[Norm, Subtract @@@ Partition[Transpose[steps], 2, 1], {2}];
    {Mean[#], Median[#], StandardDeviation[#]} & /@ norms
   ],
   {c, 0, 10, 10 / 100},
   {a, 1, 21, 20 / 100}];
```

Now

Thu 21 Sep 2017 11:32:18 GMT−7.

Space4:

```
space4 =
  ParallelTable[Module[{initPos, initVel, parameters, steps, norms, n, s}, s = 1;
    n = 200;
    initPos = RandomReal[{-1, 1}, {n, 2}];
    initVel = RandomReal[{-1, 1}, {n, 2}];
    parameters =
     Table[{a(*alignment*), s(*seperation*), c(*cohesion*), 0(*species*),
       1(*mass*), 0.3(*visibility radius*), 0.01(*max velocity*),
       0.001(*max acceleration*), 0.025(*seperation radius*), 1.0
       (*fear*), 0(*predator frames*), 10(*frames to death*)}, {n}];
    steps = runBoids[1000, 500, initPos, initVel, parameters];
    norms = Map[Norm, Subtract @@@ Partition[Transpose[steps], 2, 1], {2}];
    {Mean[#], Median[#], StandardDeviation[#]} & /@ norms],
   {c, 0, 10, 10 / 100},
   {a, 1, 21, 20 / 100},
   100];
```

Space:

```
Table[Module[{initPos, initVel, parameters, steps, norms, n},
  n = 200;
  initPos = RandomReal[{-1, 1}, {n, 2}];
  initVel = RandomReal[{-1, 1}, {n, 2}];
  parameters =
   Table[{a(*alignment*), s(*seperation*), c(*cohesion*), 0(*species*),
     1(*mass*), 0.3(*visibility radius*), 0.01(*max velocity*), 0.001
     (*max acceleration*), 0.025(*seperation radius*), 1.0(*fear*),
     0(*predator frames*), 10(*frames to death*)}, {n}];
  steps = runBoids[1000, 2, initPos, initVel, parameters];
  norms = Norm /@ (Subtract @@@ steps[[All, -2 ;;]]);
  {Mean[norms], Median[norms], StandardDeviation[norms]}
 ],
 {c, 0, 10, 10 / 100},
 {a, 1, 21, 20 / 100},
 {s, 1, 11, 10 / 100}]
$Aborted
```

Space2:

```
Table[Module[{initPos, initVel, parameters, steps, norms, n},
  n = 200;
  initPos = RandomReal[{-1, 1}, {n, 2}];
  initVel = RandomReal[{-1, 1}, {n, 2}];
  parameters =
   Table[{a(*alignment*), s(*seperation*), c(*cohesion*), 0(*species*),
     1(*mass*), 0.3(*visibility radius*), 0.01(*max velocity*), 0.001
     (*max acceleration*), 0.025(*seperation radius*), 1.0(*fear*),
     0(*predator frames*), 10(*frames to death*)}, {n}];
  steps = runBoids[1000, 2, initPos, initVel, parameters];
  norms = Norm /@ (Subtract @@@ steps[[All, -2 ;;]]);
  {Mean[norms], Median[norms], StandardDeviation[norms]}
 ],
 {c, 0, 40, 40 / 100},
 {a, 1, 71, 70 / 100},
 {s, 1, 51, 50 / 100}]
$Aborted
```

Will finish at 5:30am on Tuesday the 19th

```
Norm /@ (Subtract @@@ steps[[All, -2 ;;]])
```

```
{0.01, 0.01, 0.01, 0.00987525, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01,
 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01,
 0.01, 0.01, 0.00865782, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01,
 0.00911974, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01,
 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01,
 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01,
 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.00705106,
 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01}
```

```
space = Get[FileNameJoin[{NotebookDirectory[], "space.wl"}]];
```

```
space2 = Get[FileNameJoin[{NotebookDirectory[], "space2.wl"}]];
```

```
space3 = Get[FileNameJoin[{NotebookDirectory[], "space3.wl"}]];
```

```
Get[FileNameJoin[{NotebookDirectory[], "space4.mx"}]];
```

```
Dimensions[space]
```

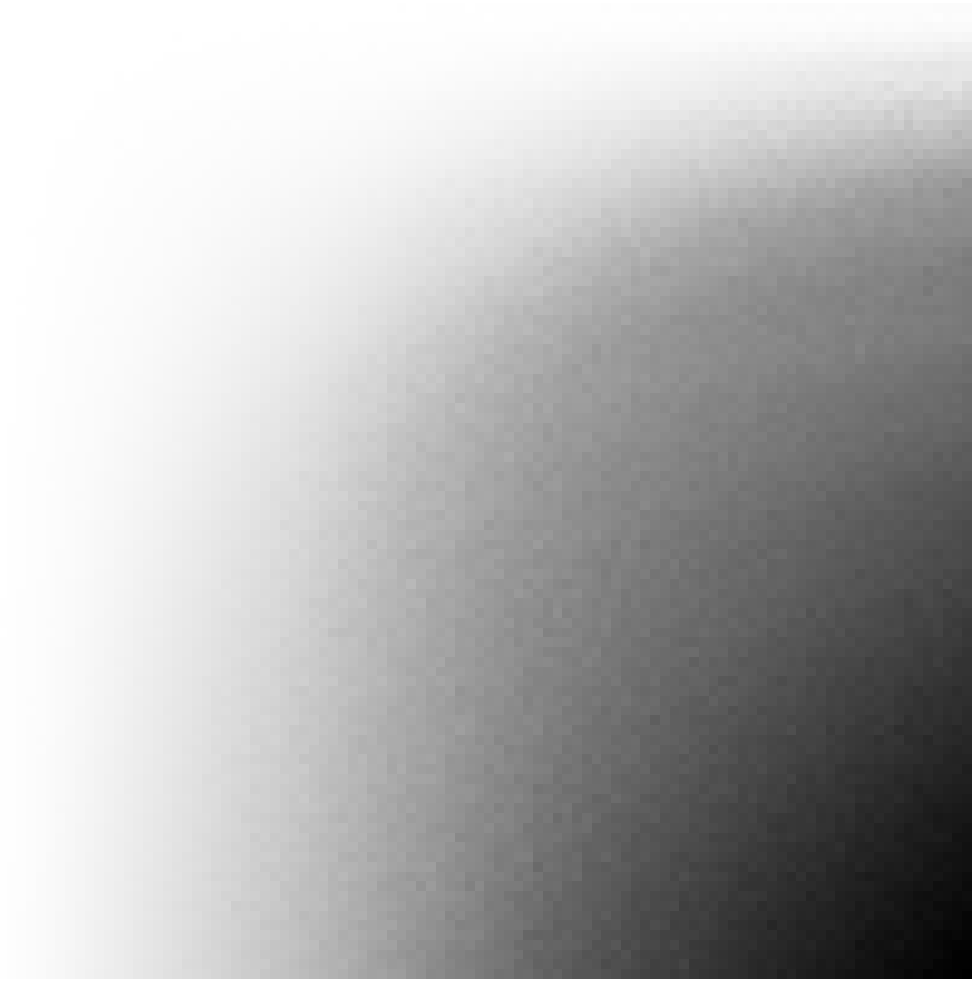
```
{101, 101, 101, 3}
```

```
Dimensions[space3]
```

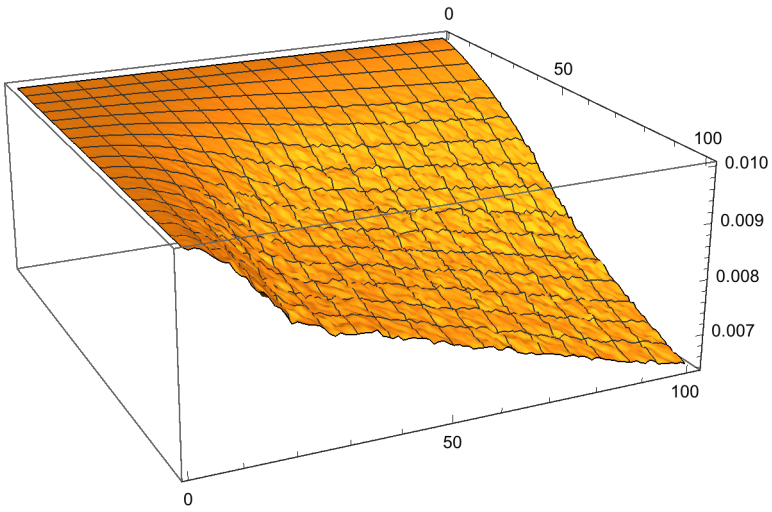
```
{101, 101, 499, 3}
```

```
means = Map[Mean, space4[[All, All, All, All, 1]], {2, 3}];
```

```
ImageAdjust@Image@means
```

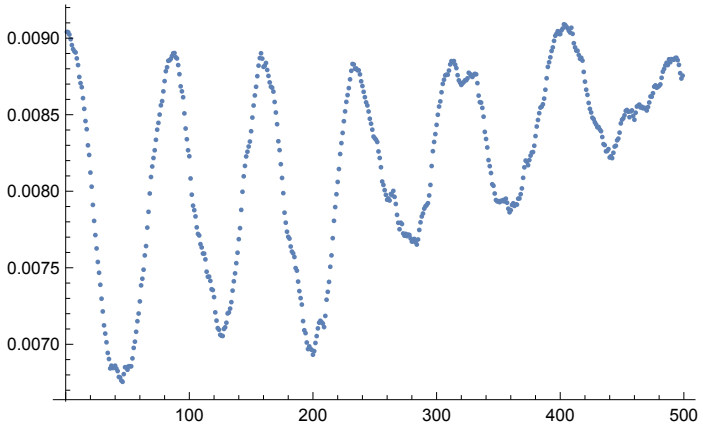


```
ListPlot3D[means]
```

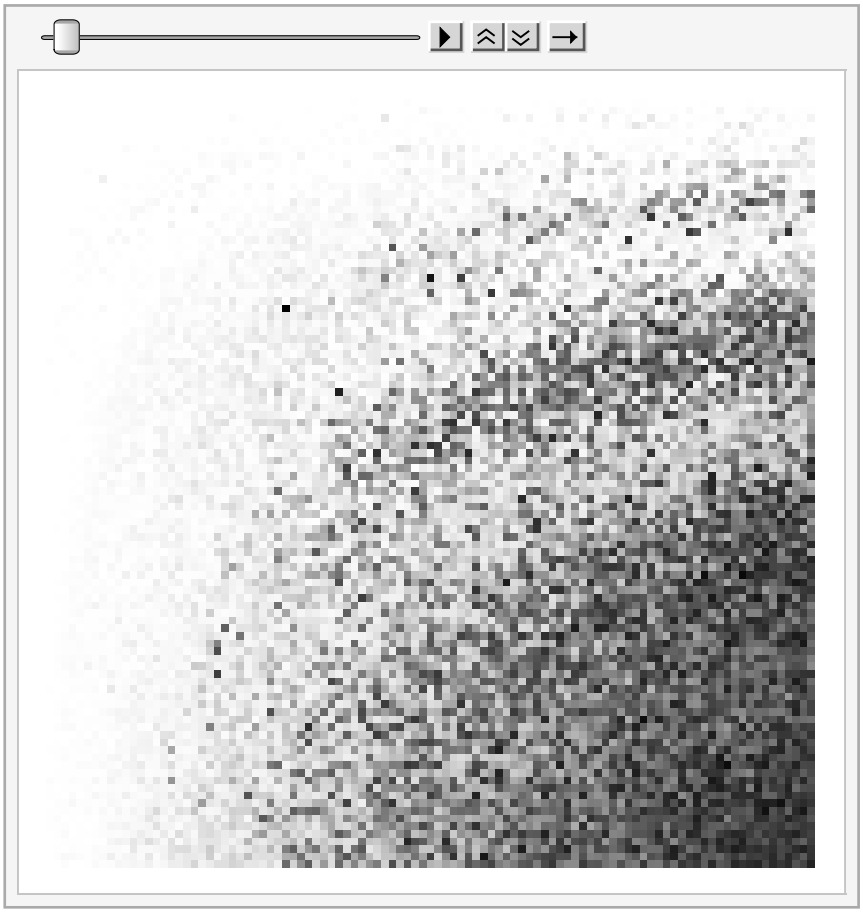


```
ListAnimate[Table[
  ImageAdjust@Image[Map[Mean, space4[[All, All, n, All, 1]], {2}], ImageSize → 400],
  {n, 1, 100, 1}], AnimationRunning → False]
```

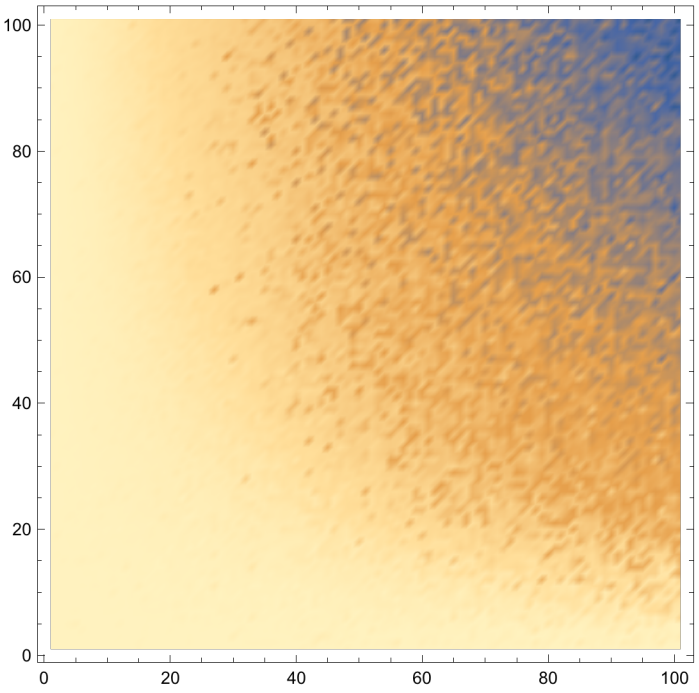
```
ListPlot@space3[[100, 52, All, 1]]
```



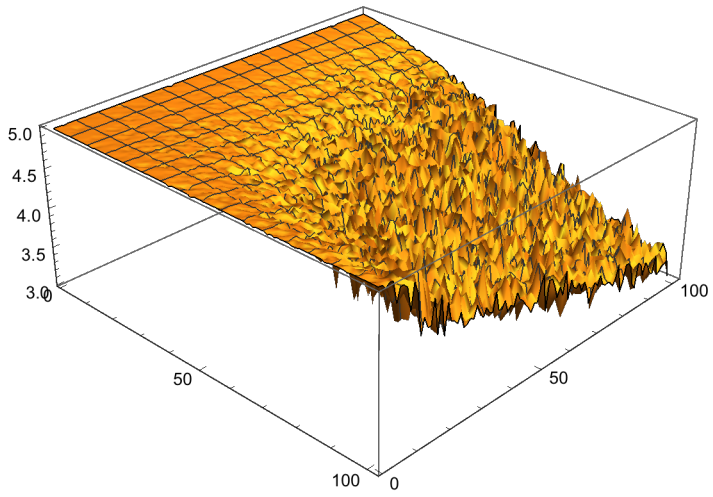
```
ListAnimate[Table[ImageAdjust@Image[space3[[All, All, n, 1]]], ImageSize → 400],
  {n, 1, 499, 1}], AnimationRunning → False]
```



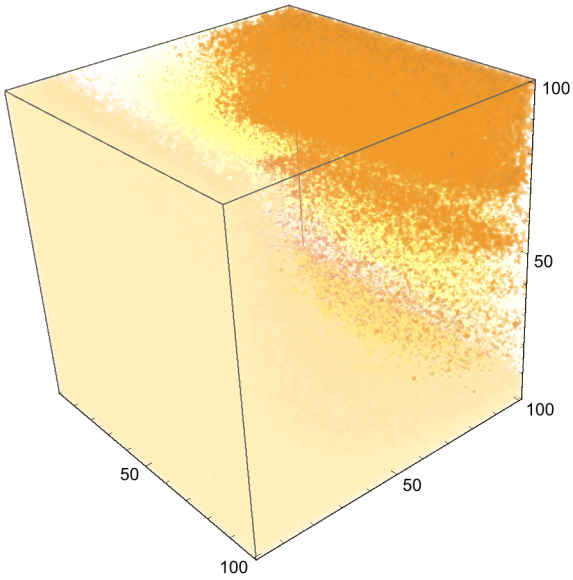
```
ListDensityPlot@Map[Total, space3[[All, All, All, 1]], {2}]
```



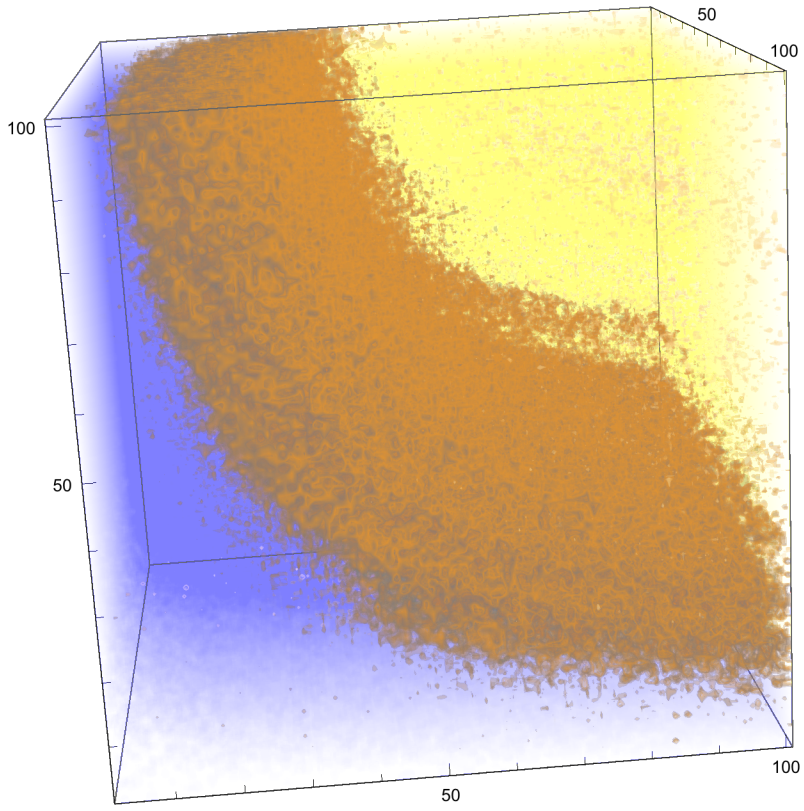

```
ListPlot3D[Map[Total, space3[[All, All, All, 1]], {2}]]
```



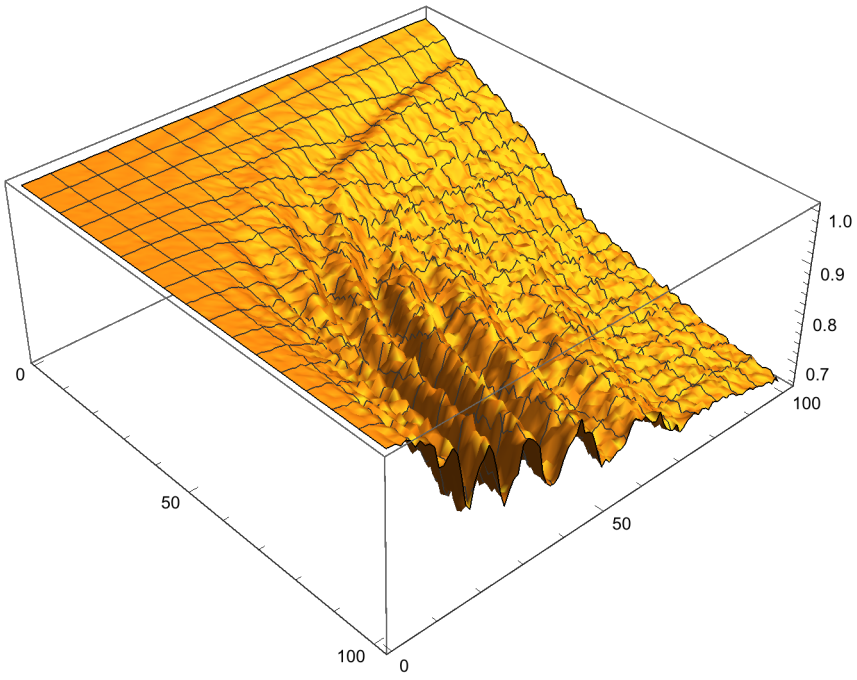
```
ListDensityPlot3D@space[[All, All, All, 1]]
```



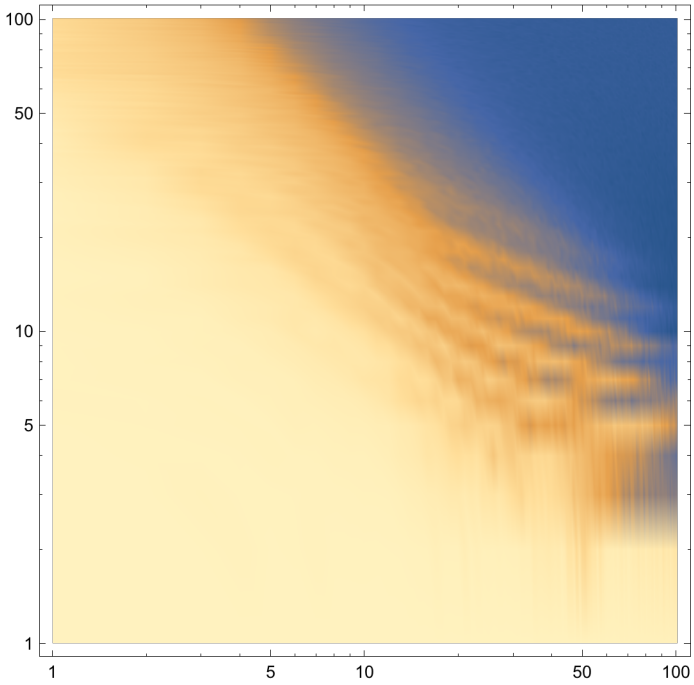

```
ListDensityPlot3D@space[[All, All, All, 3]]
```



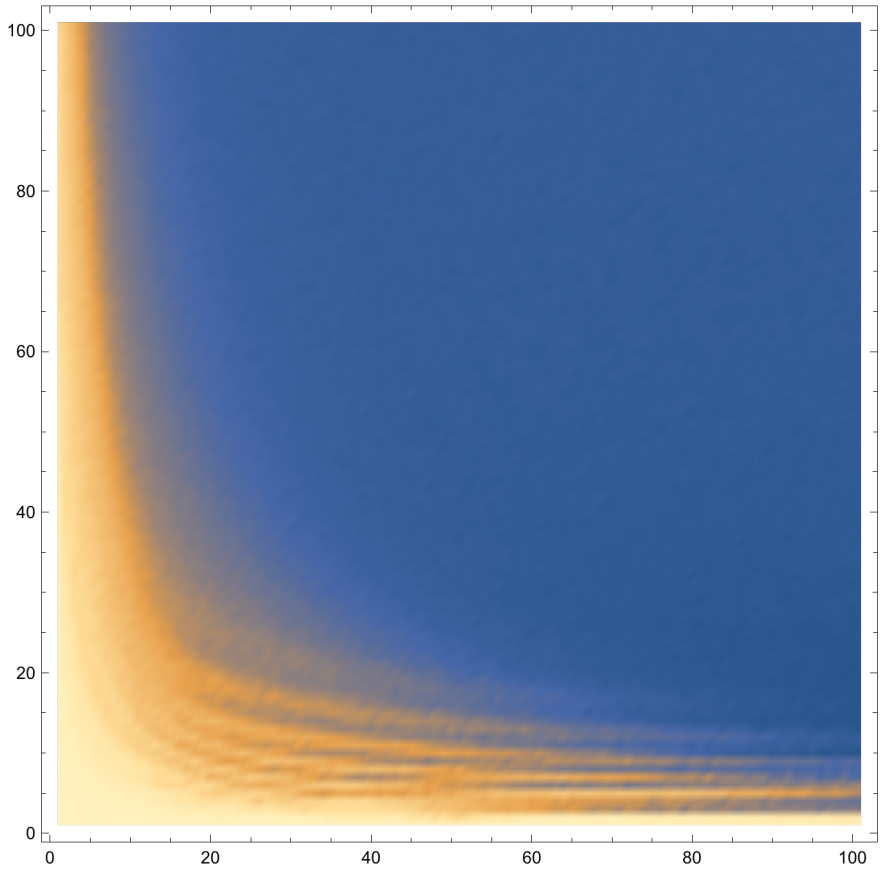
```
ListPlot3D[Map[Total, space[[All, All, All, 1]], {2}]]
```



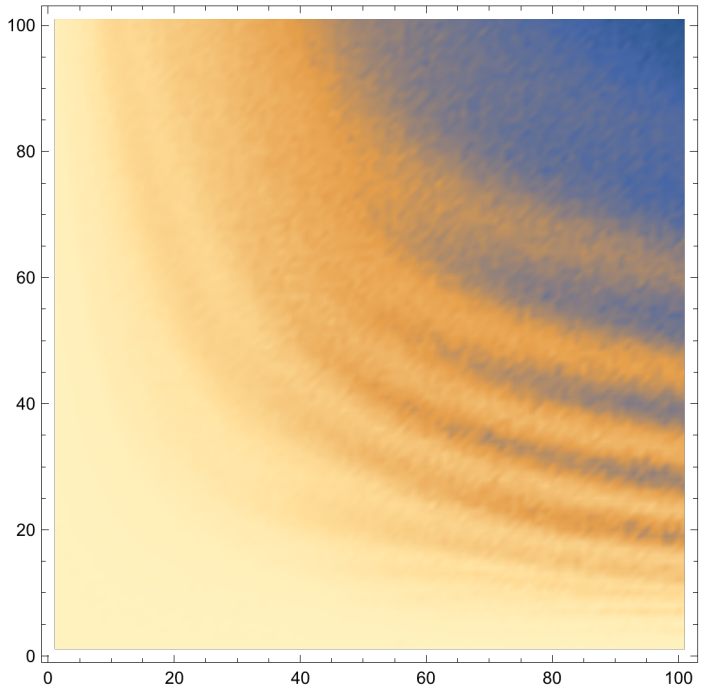

```
ListDensityPlot[Map[Total, space2[[All, All, All, 1]], {2}],
 ScalingFunctions → {"Log", "Log"}]
```



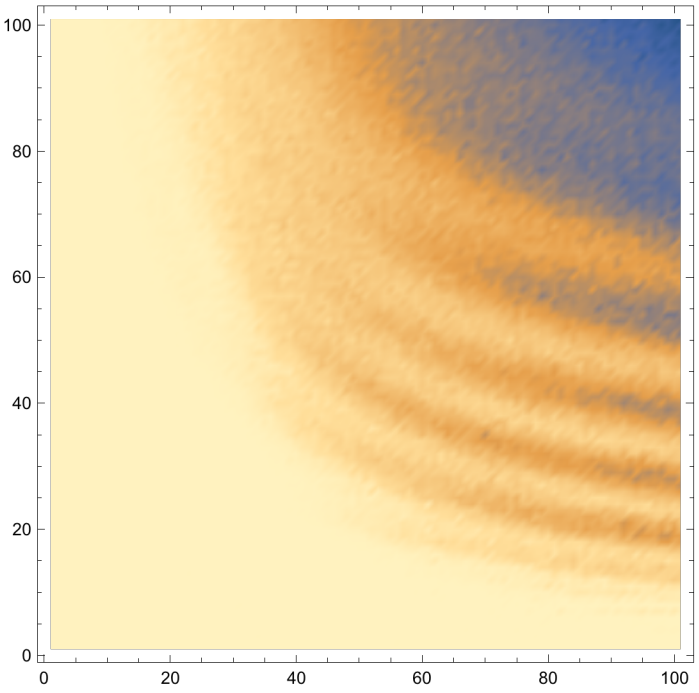
```
ListDensityPlot[Map[Total, space2[[All, All, All, 1]], {2}]]
```



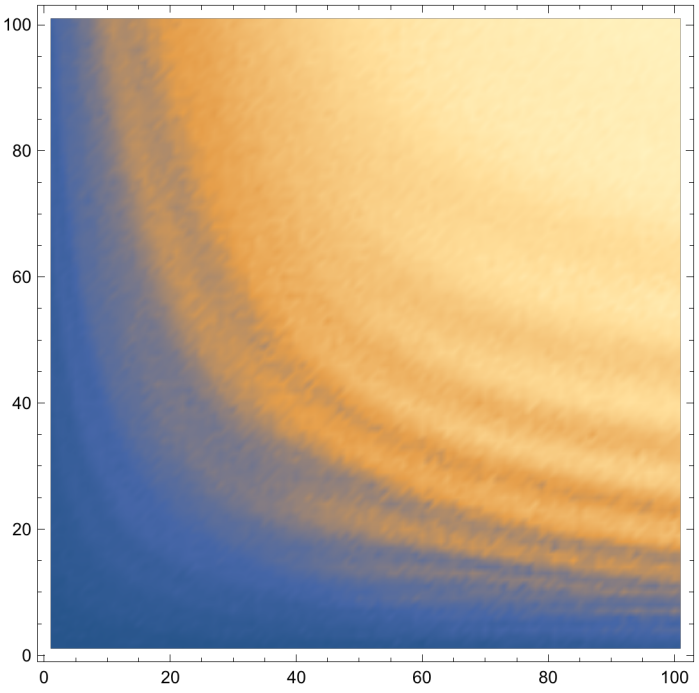

```
ListDensityPlot[Map[Total, space[[All, All, All, 1]], {2}]]
```



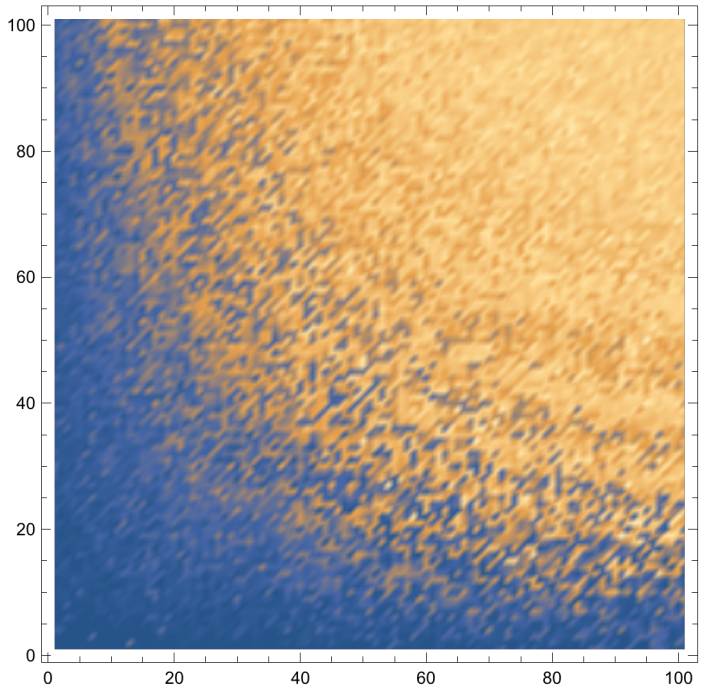
```
ListDensityPlot[Map[Total, space[[All, All, All, 2]], {2}]]
```




```
ListDensityPlot[Map[Total, space[[All, All, All, 3]], {2}]]
```



```
ListDensityPlot@space[[All, All, 50, 3]]
```

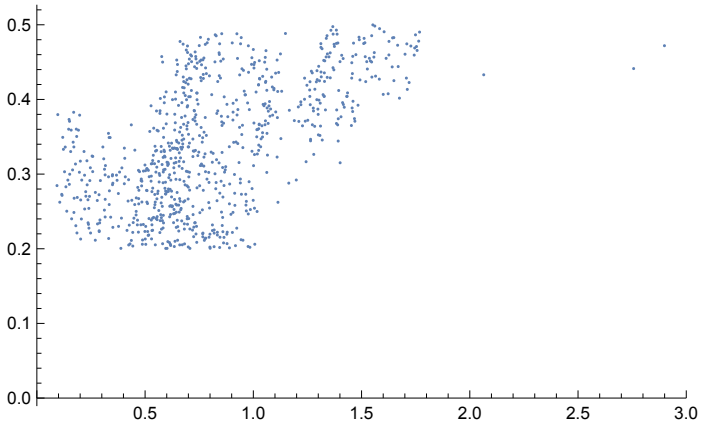


With Predators

Variable visibility radii:

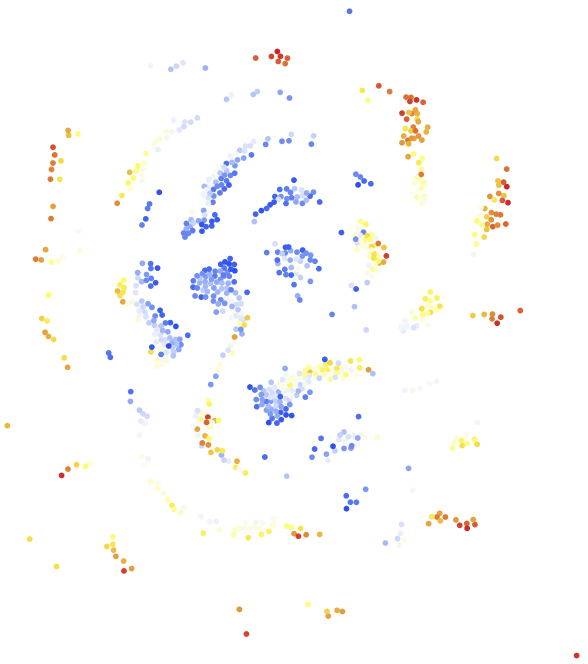
```
initPos = RandomReal[{-1, 1}, {1000, 2}];
initVel = RandomReal[{-1, 1}, {1000, 2}];
parameters = Table[
    {10(*alignment*), 1(*seperation*), 1(*cohesion*), RandomChoice[{0, 1, 3, 4}]
     (*species*), 1(*mass*), RandomReal[{0.2, 0.5}](*visibility radius*), 0.01
     (*max velocity*), 0.001(*max acceleration*), 0.025(*seperation radius*),
     1.0(*fear*), 0(*predator frames*), 10(*frames to death*)}, {1000}];

steps = runBoids[10 000, 10 000, initPos, initVel, parameters];

boidColors = ColorData["TemperatureMap"] /@ Rescale[parameters[[All, 6]]];

Manipulate[Graphics[MapThread[{#2, Point[#1]} &, {steps[[All, n]], boidColors}],
  PlotRange → 2], {n, 1, Length@First@steps, 1}]
```

```
center = Mean[steps[[All, -1]]];
ListPlot[Transpose[{EuclideanDistance[center, #] & /@ steps[[All, -1]],
    parameters[[All, 6]]}], PlotRange → {{0, 3}, All}]
```




```
Manipulate[center = Mean[steps[[All, n]]];
 ListPlot[Transpose[
   {EuclideanDistance[center, #] & /@ steps[[All, n]], parameters[[All, 6]]}],
  PlotRange → {{0, 3}, All}], {n, 1, Length@First@steps, 1}]
```

```
Graphics[
 MapThread[{#2, Point[#1]} &, {steps[[All, 10 000]], boidColors}], PlotRange → 2]
```



Persistent Homology