Fitnesses

In[ ]:=

```
θ[x_, thresh_] := If[x < thresh, 0, 1];
V[S_, p_, q_, r_, k_] := Binomial[S - 1, k] (p/(1 - r))^k (q/(1 - r))^(S-1-k);

πD[b_, num_, thresh_] := b θ[num, thresh] + 1;
πC[b_, c_, num_, thresh_] :=
  πD[b, num, thresh] - c/num θ[num, thresh] - c/thresh (1 - θ[num, thresh]);

πintraD[d_, b_, c_, num_, ω_] := b/d Sum[ω^i, {i, 0, num-1}];
πintraC[d_, b_, c_, num_, ω_] := πintraD[d, b, c, num, ω] - c;

PintraD[S_, p_, q_, r_, d_, b_, c_, ω_] := Sum[V[S, p, q, r, k] × πintraD[d, b, c, k, ω], {k, 0, S-1}];
PinterD[S_, p_, q_, r_, b_, thresh_] := Sum[V[S, p, q, r, k] × πD[b, k, thresh], {k, 0, S-1}];
PintraC[S_, p_, q_, r_, d_, b_, c_, ω_] :=
  Sum[V[S, p, q, r, k] × πintraC[d, b, c, k + 1, ω], {k, 0, S-1}];
PinterC[S_, p_, q_, r_, b_, thresh_] := Sum[V[S, p, q, r, k] × πC[b, c, k + 1, thresh], {k, 0, S-1}];

fD[d_, dintra_, x1_, x2_, z1_, y1_,
   y2_, z2_, b_, c_, bintra_, cintra_, thresh_, ω_, p_] :=
  p (Sum[(Binomial[d - 1, S - 1] (1 - z2)^(S-1) z2^(d-S) PinterD[S, y1, y2, z2, b, thresh]), {S, 2, d-1}]) +
   (1 - p) (Sum[(Binomial[dintra - 1, S - 1] (1 - z1)^(S-1) z1^(d-S)
        PintraD[S, x1, x2, z1, dintra, bintra, cintra, ω]), {S, 2, dintra-1}]);

fC[d_, dintra_, x1_, x2_, z1_, y1_,
   y2_, z2_, b_, c_, bintra_, cintra_, thresh_, ω_, p_] :=
  p (Sum[(Binomial[d - 1, S - 1] (1 - z2)^(S-1) z2^(d-S) PinterC[S, y1, y2, z2, b, thresh]), {S, 2, d-1}]) +
```

$$(1-p)\left(\sum_{S=2}^{dintra-1}\left(\text{Binomial}[dintra-1,\,S-1]\,(1-z1)^{S-1}\,z1^{d-S}\right.\right.$$

$$\left.\left.\text{PintraC}[S,\,x1,\,x2,\,z1,\,dintra,\,bintra,\,cintra,\,\omega]\right)\right);$$

Dynamics

```
In[•]:= g1dot[d_, dintra_, g1_, z1_, g2_, z2_, b_,
    c_, bintra_, cintra_, thresh_, m_, ω_, p_] := m z1 g1 (1 - g1)
    (fC[d, dintra, g1 (1 - z1), (1 - g1) (1 - z1), z1, g2 (1 - z2), (1 - g2) (1 - z2), z2, b,
       c, bintra, cintra, thresh, ω, p] - fD[d, dintra, g1 (1 - z1), (1 - g1) (1 - z1),
       z1, g2 (1 - z2), (1 - g2) (1 - z2), z2, b, c, bintra, cintra, thresh, ω, p]);
  g2dot[d_, dintra_, g1_, z1_, g2_, z2_, b_,
    c_, bintra_, cintra_, thresh_, n_, ω_, p_] := n z2 g2 (1 - g2)
    (fC[d, dintra, g2 (1 - z2), (1 - g2) (1 - z2), z2, g1 (1 - z1), (1 - g1) (1 - z1), z1, b,
       c, bintra, cintra, thresh, ω, p] - fD[d, dintra, g2 (1 - z2), (1 - g2) (1 - z2),
       z2, g1 (1 - z1), (1 - g1) (1 - z1), z1, b, c, bintra, cintra, thresh, ω, p]);

  z1dot[d_, dintra_, g1_, z1_, g2_, z2_,
    b_, c_, bintra_, cintra_, thresh_, m_, ω_, p_, e1_] :=
   m e1 (1 - z1) - m z1 (1 - z1) (g1 fC[d, dintra, g1 (1 - z1), (1 - g1) (1 - z1), z1,
         g2 (1 - z2), (1 - g2) (1 - z2), z2, b, c, bintra, cintra, thresh, ω, p] -
      (1 - g1) fD[d, dintra, g1 (1 - z1), (1 - g1) (1 - z1), z1, g2 (1 - z2),
        (1 - g2) (1 - z2), z2, b, c, bintra, cintra, thresh, ω, p]);
  z2dot[d_, dintra_, g1_, z1_, g2_, z2_, b_, c_,
    bintra_, cintra_, thresh_, n_, ω_, p_, e2_] := n e2 (1 - z2) -
   n z2 (1 - z2) (g2 fC[d, dintra, g2 (1 - z2), (1 - g2) (1 - z2), z2, g1 (1 - z1),
        (1 - g1) (1 - z1), z1, b, c, bintra, cintra, thresh, ω, p] -
     (1 - g2) fD[d, dintra, g2 (1 - z2), (1 - g2) (1 - z2), z2, g1 (1 - z1),
       (1 - g1) (1 - z1), z1, b, c, bintra, cintra, thresh, ω, p])


  res[p_, q_, r_, s_, lim_] := Quiet[NDSolve[{
      g1'[t] == m z1[t] × g1[t] (1 - g1[t]) (fC[d1, d1intra, g1[t] (1 - z1[t]),
          (1 - g1[t]) (1 - z1[t]), z1[t], g2[t] (1 - z2[t]), (1 - g2[t]) (1 - z2[t]),
          z2[t], b, c, bintraforsp1, cintraforsp1, thresh1, ωforsp1, prob[t]] -
        fD[d1, d1intra, g1[t] (1 - z1[t]), (1 - g1[t]) (1 - z1[t]),
          z1[t], g2[t] (1 - z2[t]), (1 - g2[t]) (1 - z2[t]), z2[t], b, c,
          bintraforsp1, cintraforsp1, thresh1, ωforsp1, prob[t]]),
      g2'[t] == n z2[t] × g2[t] (1 - g2[t]) (fC[d2, d2intra, g2[t] (1 - z2[t]),
          (1 - g2[t]) (1 - z2[t]), z2[t], g1[t] (1 - z1[t]), (1 - g1[t]) (1 - z1[t]),
          z1[t], b, c, bintraforsp2, cintraforsp2, thresh2, ωforsp2, prob[t]] -
        fD[d2, d2intra, g2[t] (1 - z2[t]), (1 - g2[t]) (1 - z2[t]),
          z2[t], g1[t] (1 - z1[t]), (1 - g1[t]) (1 - z1[t]), z1[t], b, c,
          bintraforsp2, cintraforsp2, thresh2, ωforsp2, prob[t]]),
```

```
      z1'[t] ==
       m e1 (1 - z1[t]) - m z1[t] (1 - z1[t]) (g1[t] × fC[d1, d1intra, g1[t] (1 - z1[t]),
              (1 - g1[t]) (1 - z1[t]), z1[t], g2[t] (1 - z2[t]), (1 - g2[t]) (1 - z2[t]),
              z2[t], b, c, bintraforsp1, cintraforsp1, thresh1, ωforsp1, prob[t]] -
            (1 - g1[t]) fD[d1, d1intra, g1[t] (1 - z1[t]), (1 - g1[t] ) (1 - z1[t]),
              z1[t], g2[t] (1 - z2[t]), (1 - g2[t]) (1 - z2[t]), z2[t], b, c,
              bintraforsp1, cintraforsp1, thresh1, ωforsp1, prob[t]]),
      z2'[t] ==
       n e2 (1 - z2[t]) - n z2[t] (1 - z2[t]) (g2[t] × fC[d2, d2intra, g2[t] (1 - z2[t]),
              (1 - g2[t]) (1 - z2[t]), z2[t], g1[t] (1 - z1[t]), (1 - g1[t] ) (1 - z1[t]),
              z1[t], b, c, bintraforsp2, cintraforsp2, thresh2, ωforsp2, prob[t]] -
            (1 - g2[t]) fD[d2, d2intra, g2[t] (1 - z2[t]), (1 - g2[t]) (1 - z2[t]),
              z2[t], g1[t] (1 - z1[t]), (1 - g1[t] ) (1 - z1[t]), z1[t], b, c,
              bintraforsp2, cintraforsp2, thresh2, ωforsp2, prob[t]]),
      g1[0] == p, g2[0] == q, z1[0] == r, z2[0] == s}, {g1, g2, z1, z2}, {t, lim}]];
(*liseval[t_,rep_]:=Evaluate[{x[t],y[t]}/.rep];*)

gamea = {3, 3 / 4};
gameb = {1, 3 / 4};
gamec = {1, 4 / 3};
gamed = {3, 4 / 3};

d1 = 5;
d2 = 5;
d1intra = 5;
d2intra = 5;
thresh1 = 1;
thresh2 = 1;
b = 2;
c = 1;
bintraforsp1 = 10;
cintraforsp1 = gameb[[1]];
ωforsp1 = gameb[[2]] // N;

bintraforsp2 = 10;
cintraforsp2 = gameb[[1]];
ωforsp2 = gameb[[2]] // N;

m = 1 / 8 // N;
n = 1;
e1 = 0.05;
e2 = 0.05;

a = 0.1;
prob[t_] := 0.666 (*Sin[a t]+1/2*) ;
lim = 8000;
```

In[ ]:=
```
Manipulate[{
  ParametricPlot[
   Evaluate[{z1[time], g1[time]} /. res[p, q, r, s, lim]], {time, 0, lim},
   PlotRange → {{-0.02, 1.02}, {-0.02, 1.02}}, AspectRatio → 1, Frame → True],
  ParametricPlot[
   Evaluate[{z2[time], g2[time]} /. res[p, q, r, s, lim]], {time, 0, lim},
   PlotRange → {{-0.02, 1.02}, {-0.02, 1.02}}, AspectRatio → 1, Frame → True]},
 {{p, 0.85}, 0, 1, AngularGauge[##1, ImageSize → 100, GaugeLabels → "g1",
    PlotLabel → "Fraction Generous"] &},
 {{q, 0.5}, 0, 1, AngularGauge[##1, ImageSize → 100, GaugeLabels → "g2"] &},
 {{r, 0.2}, 0, 1, AngularGauge[##1, ImageSize → 100,
    GaugeLabels → "z1", PlotLabel → "Empty Spaces"] &},
 {{s, 0.5}, 0, 1, AngularGauge[##1, ImageSize → 100, GaugeLabels → "z2"] &},
 ControlPlacement → {Left, Left, Right, Right}]
```

Out[ ]=

In[ ]:=
```
lim = 9000;
biglissp1 = {};
colourlistsp1 = {};
lastlist = {};
For[u = 0.05, u ≤ 0.95, u = u + 0.05,
 For[v = 0.05, v ≤ 0.95, v = v + 0.05,
  lis = Flatten[Table[Evaluate[
       {z1[time], g1[time]} /. res[v, 0.5, u, 0.5, lim]], {time, 0, lim}], 1];
  AppendTo[biglissp1, lis];
  last = Evaluate[{z1[lim], g1[lim]} /. res[v, 0.5, u, 0.5, lim]];
  AppendTo[lastlist, SetAccuracy[Last[lis] // Chop, 4]];
  If[last[[1]][[1]] > 0.99, AppendTo[colourlistsp1, Black]];
  If[last[[1]][[2]] > 0.99, AppendTo[colourlistsp1, Blue]];
  If[last[[1]][[1]] < 0.99 && last[[1]][[2]] < 0.99, AppendTo[colourlistsp1, cols[[2]]]];
 ]
]
```

In[ ]:=
```
cols = Short[ColorData[24, "ColorList"], 4][[1]]
```

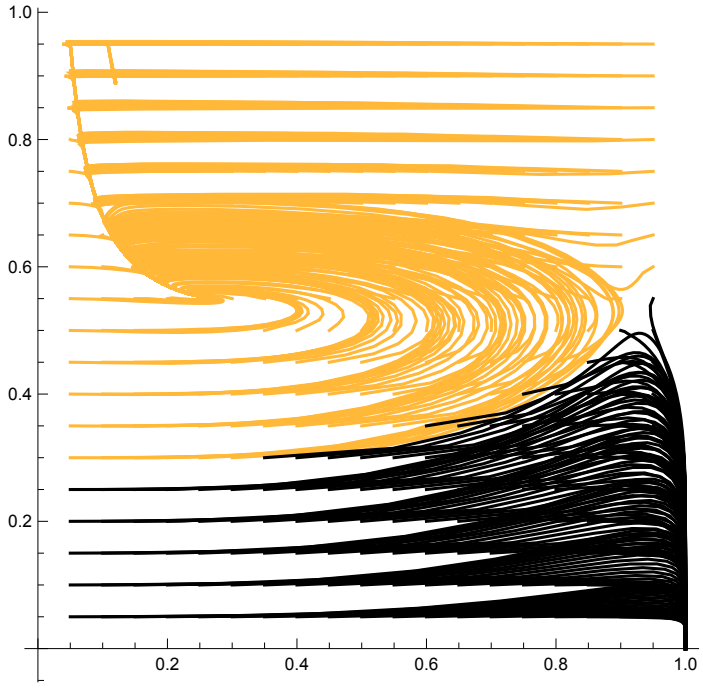
In[ ]:=
```
biglissp1 // Dimensions
```

Out[ ]=
```
{361, 9001, 2}
```

```
shortlist1 = Take[#, {1, 9001, 10}] & /@ biglissp1;
```

```
list1pl =
 ListPlot[shortlist1, Joined → True, AspectRatio → 1, PlotStyle → colourlistsp1]
```

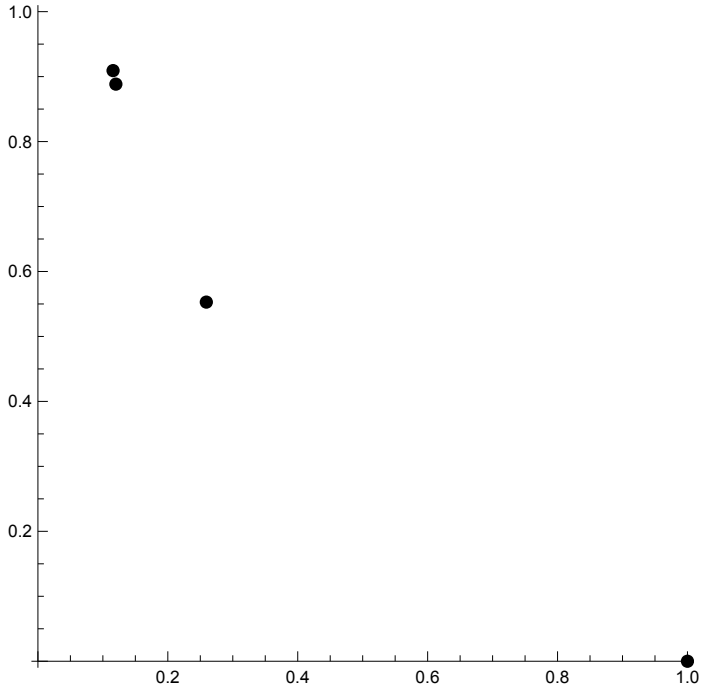
Out[ ]=



In[ ]:=
```
ptstopl = Tally[SetAccuracy[lastlist, 2]][[All, 1]];
```

In[ ]:=
```
fp1 = ListPlot[ptstopl, Joined → False, PlotRange → {{-0.01, 1.01}, {-0.01, 1.01}},
  AspectRatio → 1, PlotStyle → Directive[Black, PointSize[0.02]]]
```

Out[ ]=

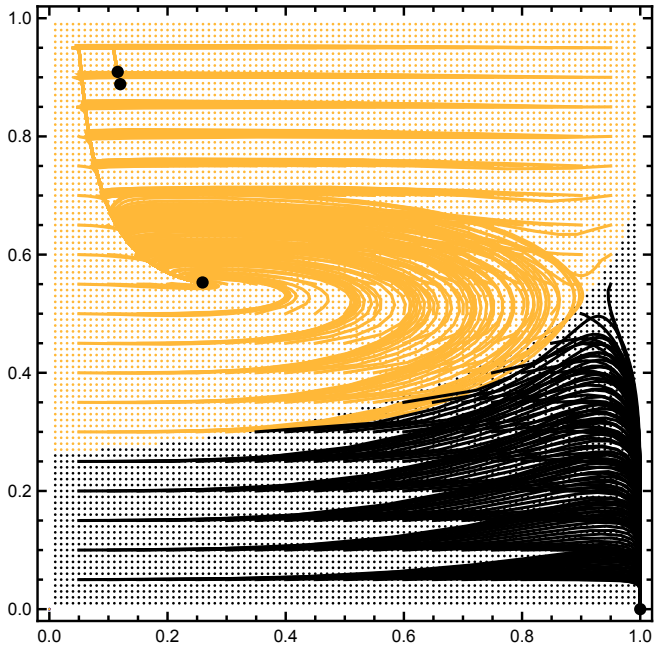


In[ ]:=
```
lim = 9000;
blacklistsp1 = {{0, 0}};
bluelistsp1 = {{0, 0}};
greenlistsp1 = {{0, 0}};
For[u = 0.01, u ≤ 0.99, u = u + 0.01,
 For[v = 0.01, v ≤ 0.99, v = v + 0.01,
  last = Evaluate[{z1[lim], g1[lim]} /. res[v, 0.5, u, 0.5, lim]];
  AppendTo[lastlist, last];
  If[last[[1]][[1]] > 0.99, AppendTo[blacklistsp1, {u, v}]];
  If[last[[1]][[2]] > 0.99, AppendTo[bluelistsp1, {u, v}]];
  If[last[[1]][[1]] < 0.99 && last[[1]][[2]] < 0.99, AppendTo[greenlistsp1, {u, v}]];
 ]
]
```

In[ ]:=
```
detailedplot1 = ListPlot[{blacklistsp1, bluelistsp1, greenlistsp1},
   PlotStyle → {Black, Blue, cols[[2]]}, AspectRatio → 1,
   PlotRange → {{-0.02, 1.02}, {-0.02, 1.02}}];
```

In[ ]:=
```
Show[detailedplot1, list1pl, fp1, Frame → True,
 FrameStyle → Thickness[0.004], ImagePadding → 20]
```

Out[ ]=

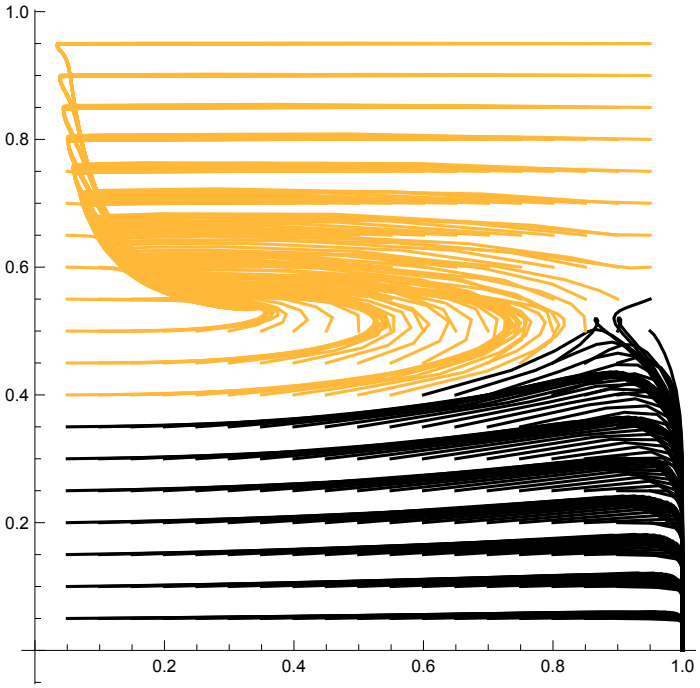


In[ ]:=
```
lim = 9000;
biglissp2 = {};
colourlistsp2 = {};
lastlist2 = {};
For[u = 0.05, u ≤ 0.95, u = u + 0.05,
 For[v = 0.05, v ≤ 0.95, v = v + 0.05,
  lis = Flatten[Table[Evaluate[
       {z2[time], g2[time]} /. res[0.6, v, 0.6, u, lim]], {time, 0, lim}], 1];
  AppendTo[biglissp2, lis];
  last = Evaluate[{z2[lim], g2[lim]} /. res[0.6, v, 0.6, u, lim]];
  AppendTo[lastlist2, last];
  If[last[[1]][[1]] > 0.99, AppendTo[colourlistsp2, Black]];
  If[last[[1]][[2]] > 0.99, AppendTo[colourlistsp2, Blue]];
  If[last[[1]][[1]] < 0.99 && last[[1]][[2]] < 0.6, AppendTo[colourlistsp2, cols[[2]]]];
 ]
]
```

In[ ]:=
```
shortlist2 = Take[#, {1, 9001, 2}] & /@ biglissp2;
```

In[ ]:=
```
list2pl =
 ListPlot[shortlist2, Joined → True, AspectRatio → 1, PlotStyle → colourlistsp2]
```

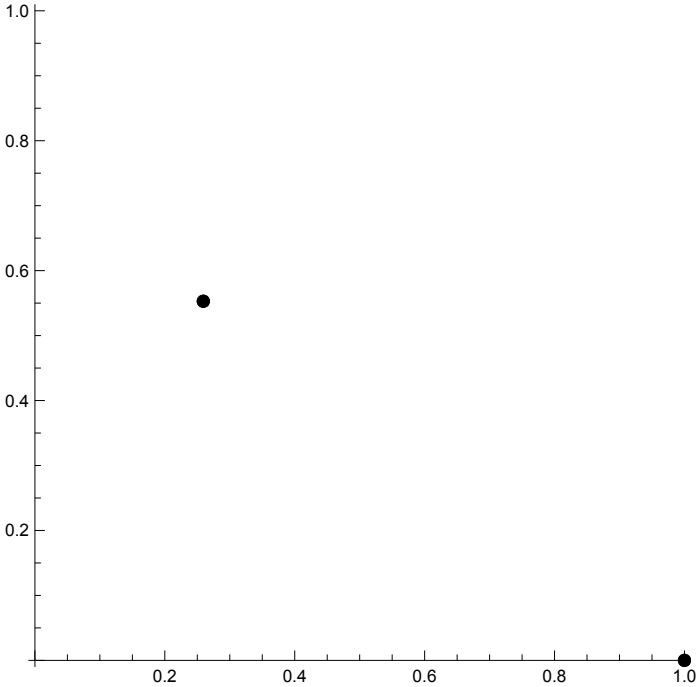
Out[ ]=



In[ ]:=
```
ptstopl2 = Tally[SetAccuracy[lastlist2, 2]][[All, 1]];
```

In[ ]:=
```
fp2 = ListPlot[ptstopl2, Joined → False,
  PlotRange → {{-0.01, 1.01}, {-0.01, 1.01}}, AspectRatio → 1,
  PlotStyle → Directive[Black, PointSize[0.02]]]
```

Out[ ]=



In[ ]:=
```
lim = 9000;
blacklistsp2 = {{0, 0}};
bluelistsp2 = {{0, 0}};
greenlistsp2 = {{0, 0}};
For[u = 0.01, u ≤ 0.99, u = u + 0.01,
 For[v = 0.01, v ≤ 0.99, v = v + 0.01,
  last = Evaluate[{z2[lim], g2[lim]} /. res[0.6, v, 0.6, u, lim]];
  If[last[[1]][[1]] > 0.99, AppendTo[blacklistsp2, {u, v}]];
  If[last[[1]][[2]] > 0.99, AppendTo[bluelistsp2, {u, v}]];
  If[last[[1]][[1]] < 0.99 && last[[1]][[2]] < 0.99, AppendTo[greenlistsp2, {u, v}]];
 ]
]
```

In[ ]:=
```
detailedplot2 = ListPlot[{blacklistsp2, bluelistsp2, greenlistsp2},
   PlotStyle → {Black, Blue, cols[[2]]}, AspectRatio → 1,
   PlotRange → {{-0.02, 1.02}, {-0.02, 1.02}}];
```

In[ ]:=
```
Show[detailedplot2, list2pl, fp2, Frame → True, FrameStyle → Thickness[0.004],
 ImagePadding → 20, PlotRange → {{-0.02, 1.02}, {-0.02, 1.02}}]
```

Out[ ]=