Siesmic Reverse Time Migration

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Supermarket Acquistion System

Land Seismic Acquisition System

In [1]:

```
using Distributed
using Makie
using QuantEcon
using LinearAlgebra
using Interact
```

Unable to load WebIO. Please make sure WebIO works for your Jupyter client.

In [2]:

```
addprocs(4)
```

Out[2]:

```
4-element Array{Int64,1}:
 2
 3
 4
 5
```

In [3]:

```
Threads.nthreads()
```

Out[3]:

```
4
```

Forward Modelling

In [4]:

```
@everywhere function F2d(v,model,dx,nt,dt)
    (nz,nx)=size(model)
    #data=Array(Float64, nx,nt)
   data=zeros(nx,nt)
    fdm=zeros(nz,nx,3)

    #Boundary Absorbing Model
    iz=1:20
    boundary = (exp.(-( (0.015 .* (20 .- iz)).^2 ) )).^10
    boundary = boundary'

    #Forward-T Modeling
    fdm[:,:,2] = model;
    data[:,1]  = model[1,:];

    a = (v.*dt/dx).^2;    #wave equation coefficient
    b = 2 .-4 .*a;

    iz=2:(nz-1)
    ix=2:(nx-1)
    izb=1:nz-20

   snapshot=zeros(nz,nx,nt)
 for it=2:nt


  fdm[iz,ix,3]=b[iz,ix].*fdm[iz,ix,2]-fdm[iz,ix,1]+a[iz,ix].*(fdm[iz,ix.+1,2]+fd
m[iz,ix.-1,2]+
            fdm[iz.+1,ix,2]+fdm[iz.-1,ix,2])

        fdm[iz,1,3] = b[iz,1].*fdm[iz,1,2] - fdm[iz,1,1] +
        a[iz,1].*(fdm[iz,2,2] + fdm[iz.+1,1,2] + fdm[iz.-1,1,2]);
        fdm[iz,nx,3] = b[iz,nx].*fdm[iz,nx,2] - fdm[iz,nx,1] +
        a[iz,nx].*(fdm[iz,nx.-1,2] + fdm[iz.+1,nx,2] +
        fdm[iz.-1,nx,2]);
  #
        fdm[1,ix,3] = b[1,ix].*fdm[1,ix,2] -  fdm[1,ix,1] +
        a[1,ix].*(fdm[2,ix,2] + fdm[1,ix.+1,2] + fdm[1,ix.-1,2]);
        fdm[nz,ix,3]= b[nz,ix].*fdm[nz,ix,2]- fdm[nz,ix,1] +
        a[nz,ix].*(fdm[nz.-1,ix,2] + fdm[nz,ix.+1,2] + fdm[nz,ix.-1,2]);


        fdm[1 ,1 ,3] = b[1 , 1].*fdm[1 ,1 ,2] -fdm[1 ,1 ,1] +
        a[1 , 1]*(fdm[2,1,2] + fdm[1,2,2]);
        fdm[nz,1 ,3] = b[nz, 1].*fdm[nz,1 ,2] -fdm[nz,1 ,1] +
        a[nz, 1]*(fdm[nz,2,2] +fdm[nz.-1,1,2]);
        fdm[1 ,nx,3] = b[1 ,nx].*fdm[1 ,nx,2] -fdm[1 ,nx,1] +
        a[1 ,nx]*(fdm[1,nx.-1,2] +fdm[2,nx,2]);
```

```
        fdm[nz,nx,3] = b[nz,nx].*fdm[nz,nx,2] -fdm[nz,nx,1] +
        a[nz,nx]*(fdm[nz.-1,nx,2] +fdm[nz,nx.-1,2]);

        fdm[:,:,1] = fdm[:,:,2];
        fdm[:,:,2] = fdm[:,:,3];
#

     for ixb = 1:20
         fdm[izb,ixb,1] = boundary[ixb].*fdm[izb,ixb,1];
         fdm[izb,ixb,2] = boundary[ixb].*fdm[izb,ixb,2];
         ixb2 = nx.-20 .+ixb;
         fdm[izb,ixb2,1] = boundary[nx.-ixb2.+1].*fdm[izb,ixb2,1];
         fdm[izb,ixb2,2] = boundary[nx.-ixb2.+1].*fdm[izb,ixb2,2];
         izb2 = nz.-20 .+ixb;
         fdm[izb2,:,1] = boundary[nz.-izb2.+1].*fdm[izb2,:,1];
         fdm[izb2,:,2] = boundary[nz.-izb2.+1].*fdm[izb2,:,2];
    end
        data[:,it] = fdm[1,:,2];
        snapshot[:,:,it] = fdm[:,:,2];
    #data = data[21:end-20,:]';
    end
    return snapshot, data
    end
```

In [5]:

```
function ricker(f,n,dt,t0,t1)



T = dt*(n-1);
t = 0:dt:T;
tau = t.-t0;

    (t1,t2) = meshgrid(tau,t.-t1);
 s = (1 .-(t1.^2+t2 .^2).*f^2 .*pi^2).*exp.(-(t1.^2+t2 .^2).*pi^2 .*f^2);
        rw = s;
    return rw,t
end
```

Out[5]:

```
ricker (generic function with 1 method)
```

In [6]:

```
nz = 200; nx = 200;
dz = 5 ; dx = 5 ;
x = (0:nx-1)*dx;
z = (0:nz-1)*dz;
```

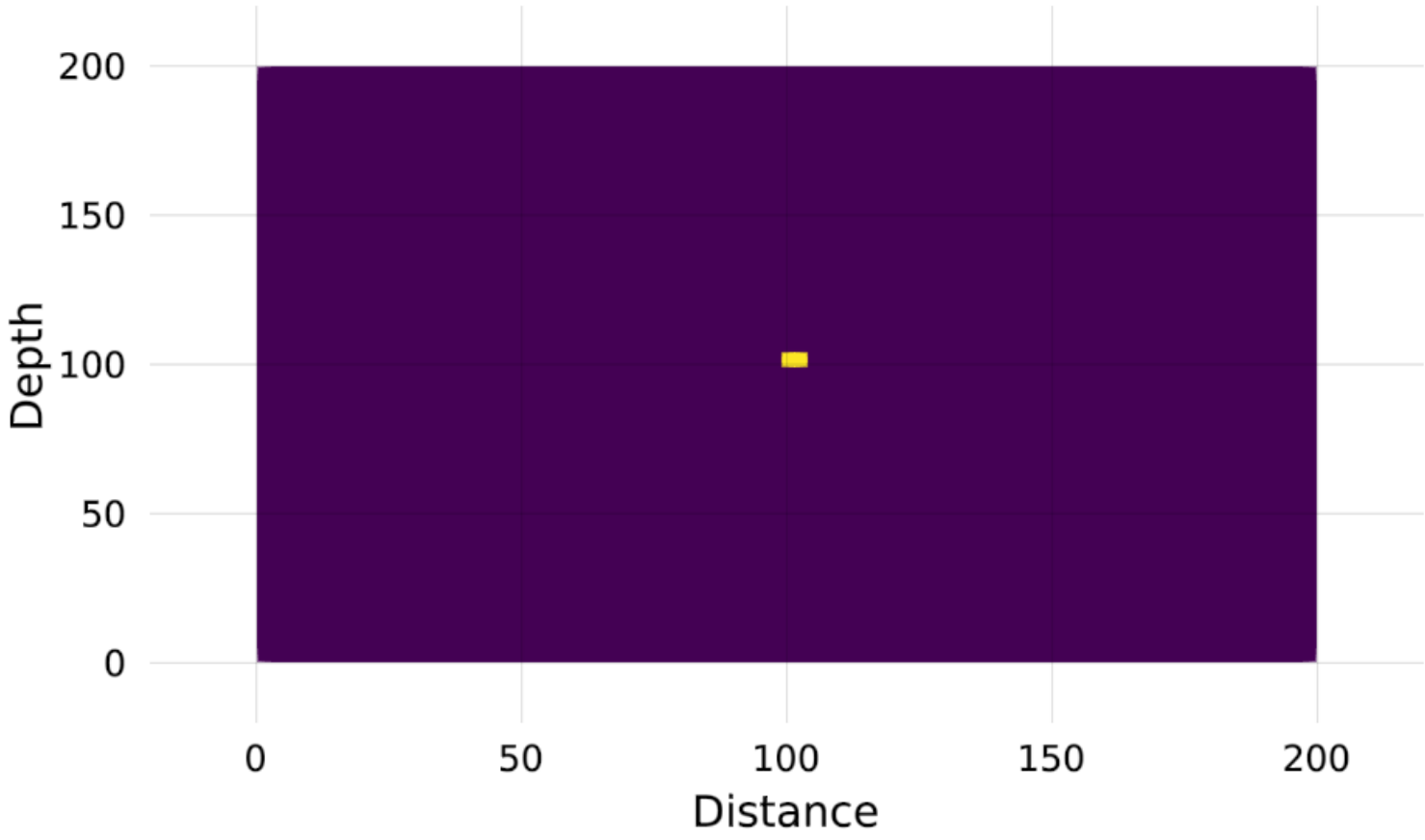
In [7]:

```
velo1 = 2000*ones(nz,nx);
velo1[Int(round(nz/2)):Int(round(nz/2)+4),Int(round(nx/2)):Int(round(nx/2)+4)] =
ones(5,5).*3000;
(g,h)=size(velo1[Int(round(nz/2)):end,1:end] )
#velo[Int(round(nz/2)):end,1:end] = ones(g,h).*3000;
```

In [8]:

```
scene = Scene()
 heatmap!(scene, velo1)
scene
 axis = scene[Axis] # get axis
 axis[:names][:axisnames] = ("Distance", "Depth")
scene
```

Out[8]:



In [9]:

```
V=zeros(nz+20,nx+40)
V = [repeat(velo1[:,1],1,20) velo1 repeat(velo1[:,end],1,20)];
V = [V;(repeat(V[end,:],1,20))'];
```

In [10]:

```
# setup source function
dt = 0.9*minimum(minimum(dz./velo1/sqrt(2)));
vmin = minimum(velo1[:,:]);
nt = Int(round(sqrt((dx*nx)^2+(dz*nz)^2)/vmin/dt*1.2+1));
t = (0:nt-1)*dt;
f = 50;
```

In [11]:

```
# initial wavefield
ixs=100

(rw,t)=ricker(f,nz+40,dt,dt*ixs,0);
rw = rw[1:nz+20,:];
    #generate shot record
       snapshot1,data1= @time F2d(V,rw,dx,nt,dt);
```

```
  7.461243 seconds (5.53 M allocations: 5.941 GiB, 19.81% gc time)
```

using Interact @manipulate for i=10:10:800 heatmap(snapshot[:,:,i]) end

@manipulate for ixs=1:20:200

(rw,t)=ricker(f,nz+40,dt,dt*ixs,0);

rw = rw[1:nz+20,:];

```
    #generate shot record
       snapshot,data= F2d(V,rw,dx,nt,dt);
```

@manipulate for i=10:10:800 heatmap(snapshot[:,:,i]) end end

p1=heatmap(data[:,end:-1:1]) p2=heatmap(data[:,end:-1:1]) pscene = AbstractPlotting.vbox(AbstractPlotting.hbox(p1, p2), sizes = [1, 1, 1])

scene = Scene();

heat = heatmap!(scene, x,z,snapshot[end:-1:1,:,1]')[end]; N = 800 scene record(scene, "./Users/Slo0oH/Documents/Classes/animated_surface_and_wireframe.mp4",1:1:N) do i heat[3]=snapshot[end:-1:1,:,i]' end

In [49]:

```
scene = Scene();
heat1 = surface!(scene, x,z,snapshot1[end:-1:1,:,1]')[end];
N = 500
scene
record(scene, "./Documents/Classes/animated_surface_and_wireframe.mp4",1:1:N) do
i
    heat1[3]=snapshot1[end:-1:1,:,i]'
end
```

```
failed process: Process(`ffmpeg -loglevel quiet -i '/var/folders/f1/
rd9jgjwn3jgbfnyv0psw07480000gn/T/tmp39y39C/##video#366.mkv' -c:v lib
x264 -preset slow -crf 24 -pix_fmt yuv420p -c:a libvo_aacenc -b:a 12
8k -y ./Documents/Classes/animated_surface_and_wireframe.mp4`, Proce
ssExited(1)) [1]

Stacktrace:
 [1] error(::String, ::Base.Process, ::String, ::Int64, ::String) at
./error.jl:42
 [2] pipeline_error at ./process.jl:695 [inlined]
 [3] #run#505(::Bool, ::Function, ::Cmd) at ./process.jl:653
 [4] run at ./process.jl:651 [inlined]
 [5] save(::String, ::VideoStream) at /Users/Slo0oH/.julia/packages/
AbstractPlotting/tmFCk/src/display.jl:273
 [6] record(::getfield(Main, Symbol("##15#16")), ::Scene, ::String,
::StepRange{Int64,Int64}) at /Users/Slo0oH/.julia/packages/AbstractP
lotting/tmFCk/src/display.jl:333
 [7] top-level scope at In[49]:5
```

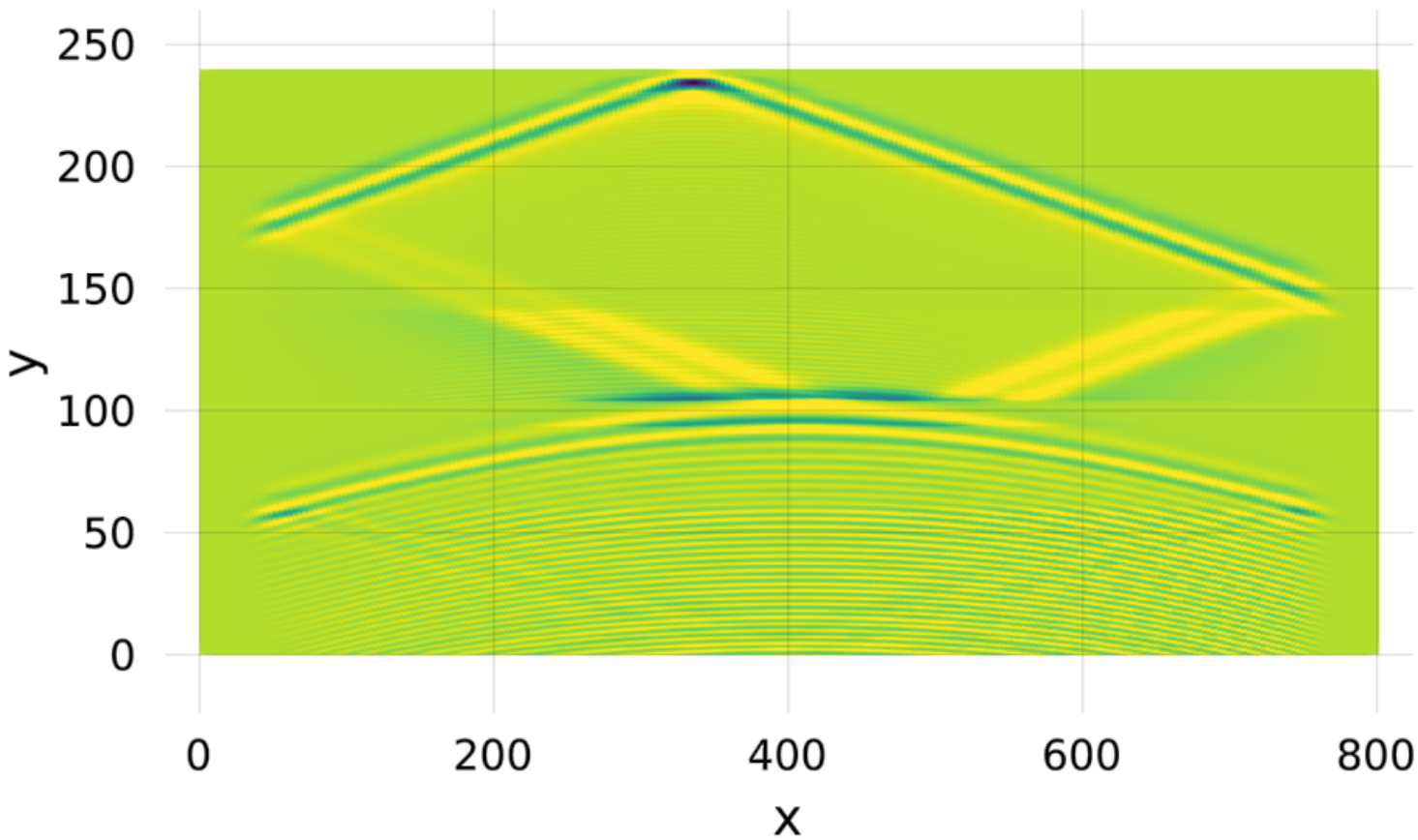
In [13]:

```
for k = 1:nt
    aux =  data1[:,k];
    amax = maximum((aux));
    data1[:,k] = data1[:,k]/amax;
   end
```

In [14]:

```
heatmap(data1[:,end:-1:1])
```

Out[14]:



scene2 = Scene(); datas=zeros(nx+40,nt)

heat = heatmap!(scene2, x,z,datas[:,:])[end]; N = 800 scene2

record(scene2, "./docs/media/animated_surface_and_wireframe.mp4",2:1:N) do i

```
    datas=zeros(nx+40,nt)
    datas[:,1:i]=data[:,1:i];
    heat[3]=datas[:,:].*100
```

end

Reverse-time Modelling

In [15]:

```
@everywhere function b2d(v,data,dx,nt,dt)
(nz,nx) = size(v);
(~,nt) = size(data);
fdm  = zeros(nz,nx,3);
    ss=zeros(nz,nx,3);
```

```
iz = 1:20;

boundary = (exp.(-( (0.015 .*(20 .-iz)).^2 ) )).^10;

fdm[1,:,1] = data[:,nt];
fdm[1,:,2] = data[:,nt-1];
fdm[1,:,3] = data[:,nt-2];

a = (v .* dt/dx) .^2;
b = 2 .- 4 .* a;


ix   = 2:nx-1;
ixb  = 1:20;
ixb2 = nx-19:nx;

cz = 3;

snapshot = zeros(nz,nx,nt);

       for it = (nt-1):-1:1
    cz = cz .+1;
    bz = min(cz,nz);

        for iz = 1:bz
        fdm[iz,ixb,1] = boundary.*fdm[iz,ixb,1];
        fdm[iz,ixb,2] = boundary.*fdm[iz,ixb,2];
        fdm[iz,ixb2,1] = boundary[end:-1:1].*fdm[iz,ixb2,1];
        fdm[iz,ixb2,2] = boundary[end:-1:1].*fdm[iz,ixb2,2];

    end

            if bz >= (nz-19)
        for iz = nz-19:bz
            fdm[iz,:,1] = boundary[nz.-iz.+1].*fdm[iz,:,1];
            fdm[iz,:,2] = boundary[nz.-iz.+1].*fdm[iz,:,2];
        end
    end

         if bz == nz
        ez = nz .-1;
    else
        ez = bz;
    end


            iz = 1:bz;
    fdm[iz,ix,3] = fdm[iz,ix,3] - fdm[iz,ix,1];

    iz = 2:ez;
    fdm[iz,ix,2] = b[iz,ix].*fdm[iz,ix,1] + fdm[iz,ix,2] + a[iz,ix.+1].*fdm[iz,i
x.+1,1] +
        a[iz,ix.-1].*fdm[iz,ix.-1,1]+ a[iz.+1,ix].*fdm[iz.+1,ix,1] + a[iz.-1,ix]
.*fdm[iz.-1,ix,1];
```

```
    fdm[1,ix,2] = b[1,ix].*fdm[1,ix,1] + fdm[1,ix,2]+ a[1,ix.+1].*fdm[1,ix.+1,1]
+
        a[1,ix.-1].*fdm[1,ix.-1,1]+ a[2,ix].*fdm[2,ix,1];


    if bz == nz


        fdm[nz,ix,2] = b[nz,ix,1].*fdm[nz,ix,1] + fdm[nz,ix,2] + a[nz,ix.+1].*fd
m[nz,ix.+1,1] +
            a[nz,ix.-1].*fdm[nz,ix.-1,1] + a[nz.-1,ix].*fdm[nz.-1,ix,1];


        fdm[nz,1,2] = b[nz,1,1].*fdm[nz,1,1] + fdm[nz,1,2] +
            a[nz,2,1].*fdm[nz,2,1] + a[nz.-1,1,1].*fdm[nz.-1,1,1];
    end

    fdm[iz,1,2] = b[iz,1,1].*fdm[iz,1,1] + fdm[iz,1,2]+
        a[iz,2].*fdm[iz,2,1]+ a[iz.+1,1].*fdm[iz.+1,1,1] +
        a[iz.-1,1].*fdm[iz.-1,1,1];

    fdm[iz,nx,2] = b[iz,nx,1].*fdm[iz,nx,1] + fdm[iz,nx,2] + a[iz,nx.-1].*fdm[iz
,nx.-1,1]+
        a[iz.+1,nx].*fdm[iz.+1,nx,1] + a[iz.-1,nx].*fdm[iz.-1,nx,1];


fdm[1,1,2] = b[1,1,1].*fdm[1,1,1] + fdm[1,1,2]+
    a[1,2,1].*fdm[1,2,1] + a[2,1,1].*fdm[2,1,1];


fdm[1,nx,2] = b[1,nx,1].*fdm[1,nx,1] + fdm[1,nx,2] +
    a[1,nx.-1,1].*fdm[1,nx.-1,1] + a[2,nx,1].*fdm[2,nx,1];


fdm[:,:,1] = fdm[:,:,2];
fdm[:,:,2] = fdm[:,:,3];


if it > 2
    fdm[2:nz,:,3] = zeros(nz-1,nx);
    fdm[1,:,3] = data[:,it-2];
end

snapshot[:,:,it] = fdm[:,:,1];
    end
model = fdm[:,:,1];
return snapshot,model
end
```

In [16]:

```
nz = Int(200); nx = Int(200);
dz = 10 ; dx = 10 ;
x = (0:nx-1)*dx;
z = (0:nz-1)*dz;
```

In [17]:

```
velo=zeros(nz,nx)
velo = 2000 .*ones(nz,nx);
velo[Int(round(nz/2)):Int(round(nz/2)+4),Int(round(nx/2)):Int(round(nx/2)+4)] =
ones(5,5).*3000;
velo_const = 2000 .*ones(nz,nx);
#velo[51:end,1:end] = 3000*ones(50,nx);
#velo[76:end,1:end] = 4000*ones(25,nx);
```

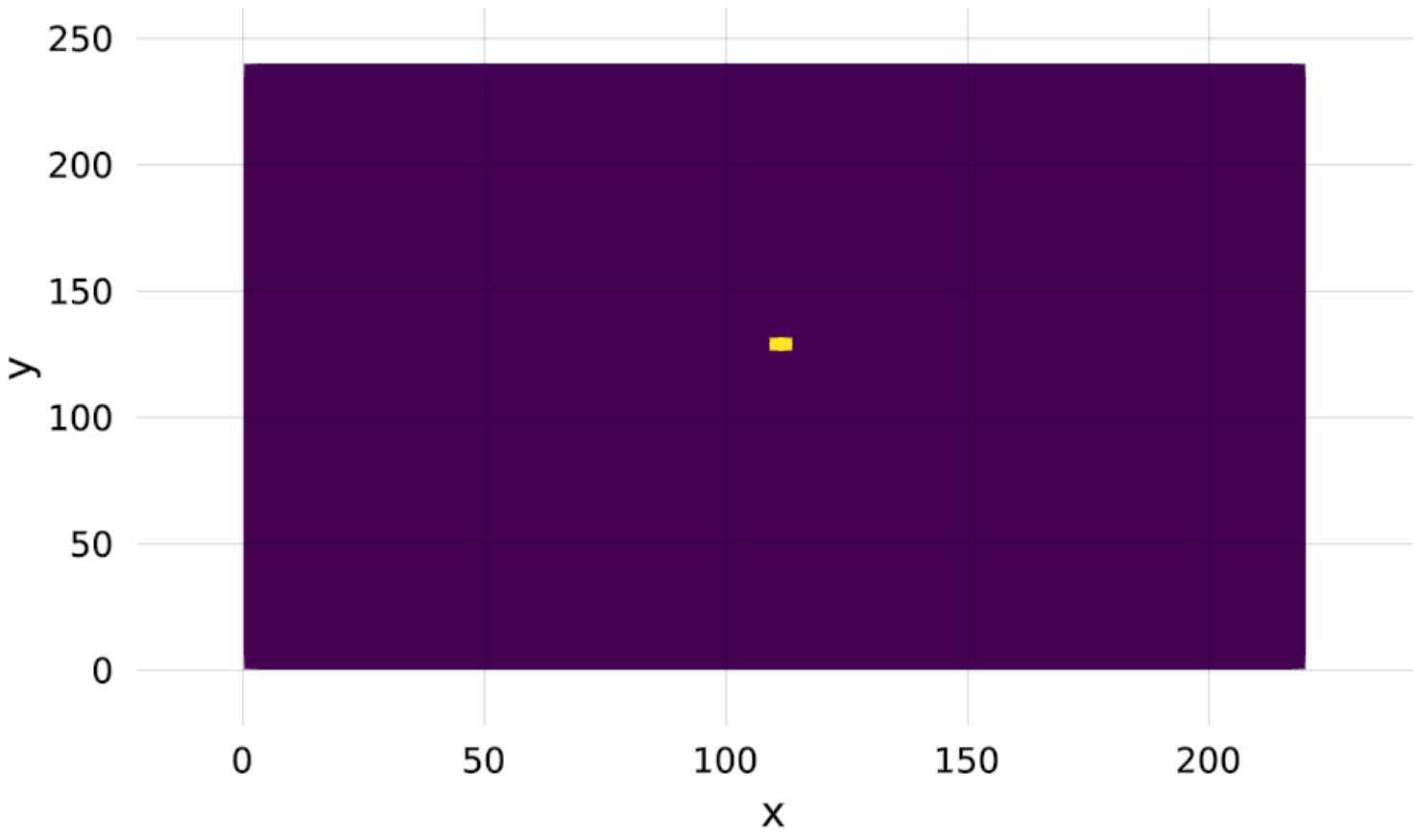
In [18]:

```
V = [repeat(velo[:,1],1,20) velo repeat(velo[:,end],1,20)];
V = [V;(repeat(V[end,:],1,20))'];
```

In [19]:

```
heatmap(V[end:-1:1,:]')
```

Out[19]:



In [20]:

```
Vc = [repeat(velo_const[:,1],1,20) velo_const repeat(velo_const[:,end],1,20)];
Vc = [Vc;(repeat(Vc[end,:],1,20))'];
```

In [21]:

```
# setup source function
dt = 0.9*minimum(minimum(dz./velo/sqrt(2)));
vmin = minimum(velo[:,:]);
nt = Int(round(sqrt((dx*nx)^2+(dz*nz)^2)/vmin/dt+1));
t = (0:nt-1)*dt;
f = 1000;
```

In [22]:

```
nt
```

Out[22]:

```
668
```

In [23]:

```
data = zeros(size(nt,nx));
snapshot_i = zeros(nz+20,nx+40,nt);
#snapshot_d = zeros(nz+20,nx+40,nt);
#snapshot_c = zeros(nz+20,nx+40,nt);
images = zeros(nz+20,nx+40);

#for ixs=1:10:100;
 ixs=100
    (rw,t) = ricker(f,nz+40,dt,dt*ixs,0);
    rw = rw[1:nz+20,:];




    (snapshot_s,data) = F2d(V,rw,dx,nt,dt);
      ( snapshot_c,data_const) = F2d(Vc,rw,dx,nt,dt);


 data_refl = data .- data_const;


   @time    (snapshot_d,fdm) = b2d(Vc,data_refl,dx,nt,dt);


      for i = 1:nt
          snapshot_i[:,:,i] = snapshot_c[:,:,i] .* snapshot_d[:,:,i];
     end
    i=2
for i = 2:nt
          snapshot_i[:,:,i] = snapshot_i[:,:,i] .+ snapshot_i[:,:,i.-1];
     end
     images = images .+ snapshot_i[:,:,end];

#end
```

```
  8.482021 seconds (4.67 M allocations: 6.214 GiB, 14.72% gc time)
```

using SharedArrays

using DistributedArrays a = SharedArray{Float64}(10) @distributed for i = 1:10 a[i] = i end

In [50]:

```
scene = Scene();

heat = heatmap!(scene, x,z,snapshot_c[end:-1:1,:,1]')[end];
N = 200
scene
record(scene, "./docs/media/animated_surface_and_wireframe.mp4",1:1:N) do i
    heat[3]=snapshot_c[end:-1:1,:,i]'
end
```

```
failed process: Process(`ffmpeg -loglevel quiet -i '/var/folders/f1/
rd9jgjwn3jgbfnyv0psw07480000gn/T/tmp2Tu1jq/##video#368.mkv' -c:v lib
x264 -preset slow -crf 24 -pix_fmt yuv420p -c:a libvo_aacenc -b:a 12
8k -y ./docs/media/animated_surface_and_wireframe.mp4`, ProcessExite
d(1)) [1]

Stacktrace:
 [1] error(::String, ::Base.Process, ::String, ::Int64, ::String) at
./error.jl:42
 [2] pipeline_error at ./process.jl:695 [inlined]
 [3] #run#505(::Bool, ::Function, ::Cmd) at ./process.jl:653
 [4] run at ./process.jl:651 [inlined]
 [5] save(::String, ::VideoStream) at /Users/Slo0oH/.julia/packages/
AbstractPlotting/tmFCk/src/display.jl:273
 [6] record(::getfield(Main, Symbol("##17#18")), ::Scene, ::String,
::StepRange{Int64,Int64}) at /Users/Slo0oH/.julia/packages/AbstractP
lotting/tmFCk/src/display.jl:333
 [7] top-level scope at In[50]:6
```

In [51]:

```
scene = Scene();

heat = heatmap!(scene, x,z,snapshot_d[end:-1:1,:,1]')[end];
N = 200
scene
record(scene, "./docs/media/animated_surface_and_wireframe.mp4",1:1:N) do i
    heat[3]=snapshot_d[end:-1:1,:,i]'
end
```

```
failed process: Process(`ffmpeg -loglevel quiet -i '/var/folders/f1/
rd9jgjwn3jgbfnyv0psw07480000gn/T/tmpU8AEgF/##video#369.mkv' -c:v lib
x264 -preset slow -crf 24 -pix_fmt yuv420p -c:a libvo_aacenc -b:a 12
8k -y ./docs/media/animated_surface_and_wireframe.mp4`, ProcessExite
d(1)) [1]

Stacktrace:
 [1] error(::String, ::Base.Process, ::String, ::Int64, ::String) at
./error.jl:42
 [2] pipeline_error at ./process.jl:695 [inlined]
 [3] #run#505(::Bool, ::Function, ::Cmd) at ./process.jl:653
 [4] run at ./process.jl:651 [inlined]
 [5] save(::String, ::VideoStream) at /Users/Slo0oH/.julia/packages/
AbstractPlotting/tmFCk/src/display.jl:273
 [6] record(::getfield(Main, Symbol("##19#20")), ::Scene, ::String,
::StepRange{Int64,Int64}) at /Users/Slo0oH/.julia/packages/AbstractP
lotting/tmFCk/src/display.jl:333
 [7] top-level scope at In[51]:6
```

In [52]:

```
scene = Scene();

heat = heatmap!(scene, x,z,snapshot_i[end:-1:1,:,1]')[end];
N = 400
scene
record(scene, "./docs/media/animated_surface_and_wireframe.mp4",1:1:N) do i
    heat[3]=snapshot_i[end:-1:1,:,i]'
end
```

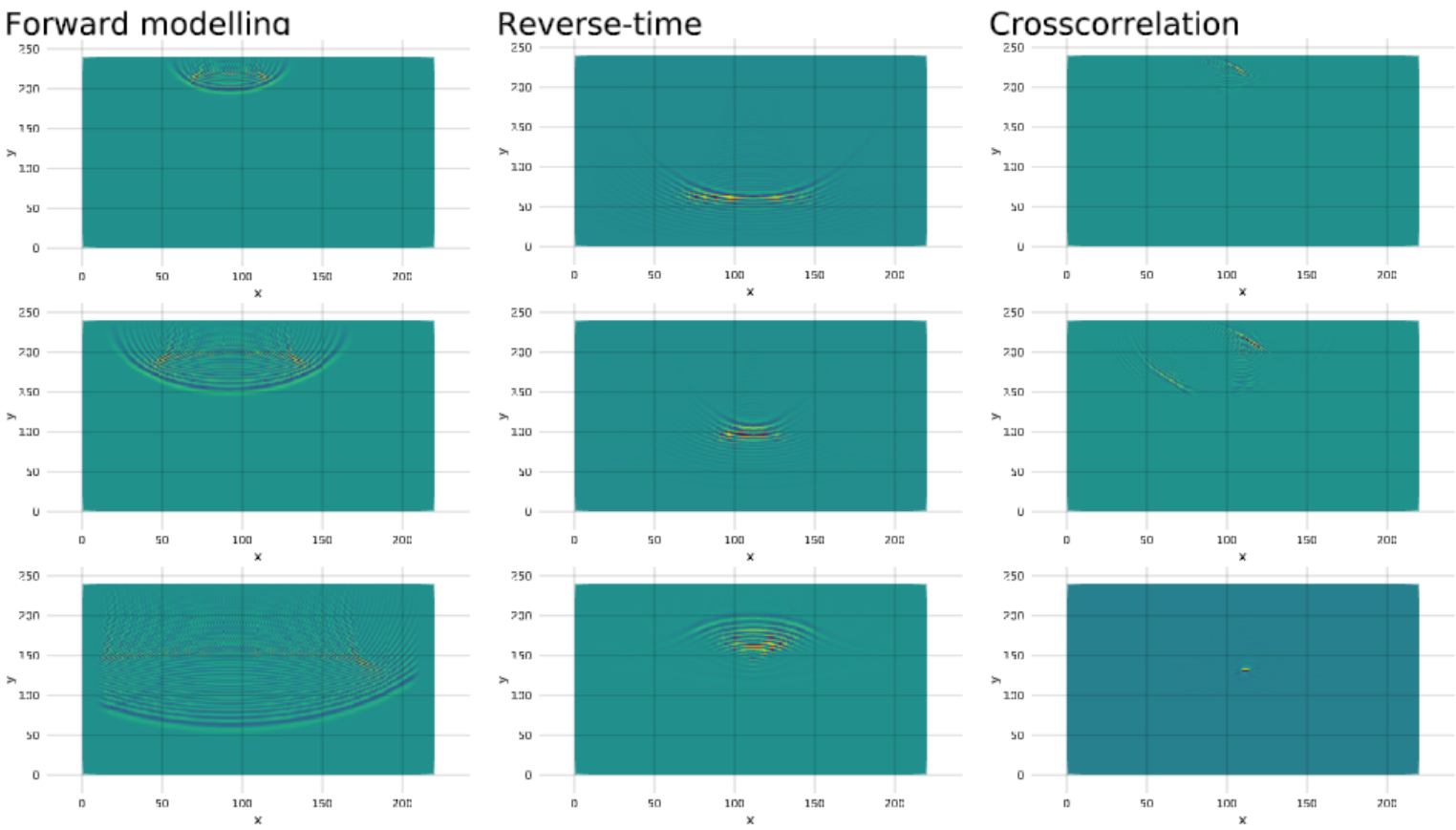
```
failed process: Process(`ffmpeg -loglevel quiet -i '/var/folders/f1/
rd9jgjwn3jgbfnyv0psw07480000gn/T/tmplz9UFs/##video#370.mkv' -c:v lib
x264 -preset slow -crf 24 -pix_fmt yuv420p -c:a libvo_aacenc -b:a 12
8k -y ./docs/media/animated_surface_and_wireframe.mp4`, ProcessExite
d(1)) [1]

Stacktrace:
 [1] error(::String, ::Base.Process, ::String, ::Int64, ::String) at
./error.jl:42
 [2] pipeline_error at ./process.jl:695 [inlined]
 [3] #run#505(::Bool, ::Function, ::Cmd) at ./process.jl:653
 [4] run at ./process.jl:651 [inlined]
 [5] save(::String, ::VideoStream) at /Users/Slo0oH/.julia/packages/
AbstractPlotting/tmFCk/src/display.jl:273
 [6] record(::getfield(Main, Symbol("##21#22")), ::Scene, ::String,
::StepRange{Int64,Int64}) at /Users/Slo0oH/.julia/packages/AbstractP
lotting/tmFCk/src/display.jl:333
 [7] top-level scope at In[52]:6
```

In [27]:

```
p1 = heatmap(snapshot_c[end:-1:1,:,100]')
p2 = heatmap(snapshot_d[end:-1:1,:,100]')
p3 = heatmap(snapshot_i[end:-1:1,:,100]')
p4 = heatmap(snapshot_c[end:-1:1,:,200]')
p5 = heatmap(snapshot_d[end:-1:1,:,200]')
p6 = heatmap(snapshot_i[end:-1:1,:,200]')
p7 = heatmap(snapshot_c[end:-1:1,:,400]')
p8 = heatmap(snapshot_d[end:-1:1,:,400]')
p9 = heatmap(snapshot_i[end:-1:1,:,400]')
 t = Theme(align = (:left, :bottom), raw = true, camera = campixel!)
 title1 = text(t, "Forward modelling")
 title2 = text( t,"Reverse-time")
 title3 = text( t,"Crosscorrelation")
 pscene = AbstractPlotting.vbox(AbstractPlotting.hbox(p7,p4,p1,title1), Abstract
Plotting.hbox(p8,p5,p2,title2),
    AbstractPlotting.hbox(p9,p6,p3,title3)
 )
```

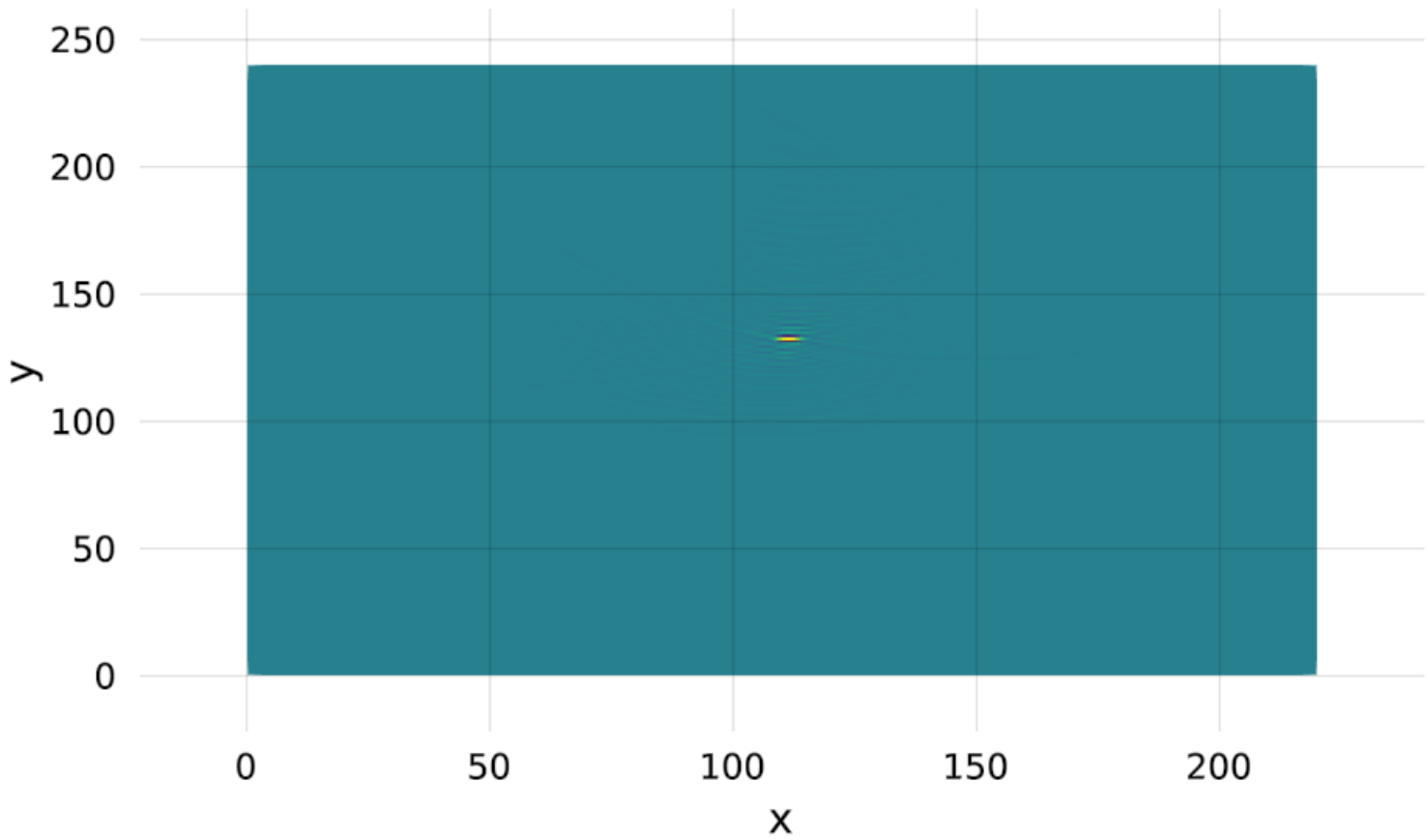
Out[27]:



In [29]:

```
heatmap(images[end:-1:1,:]')
```

Out[29]:



In [30]:

```
using Images, Interact
```

download("https://upload.wikimedia.org/wikipedia/commons/6/69/Julia_prog_language.svg (https://upload.wikimedia.org/wikipedia/commons/6/69/Julia_prog_language.svg)")

In [31]:

```
julia = load("julia.png")
```

Out[31]:

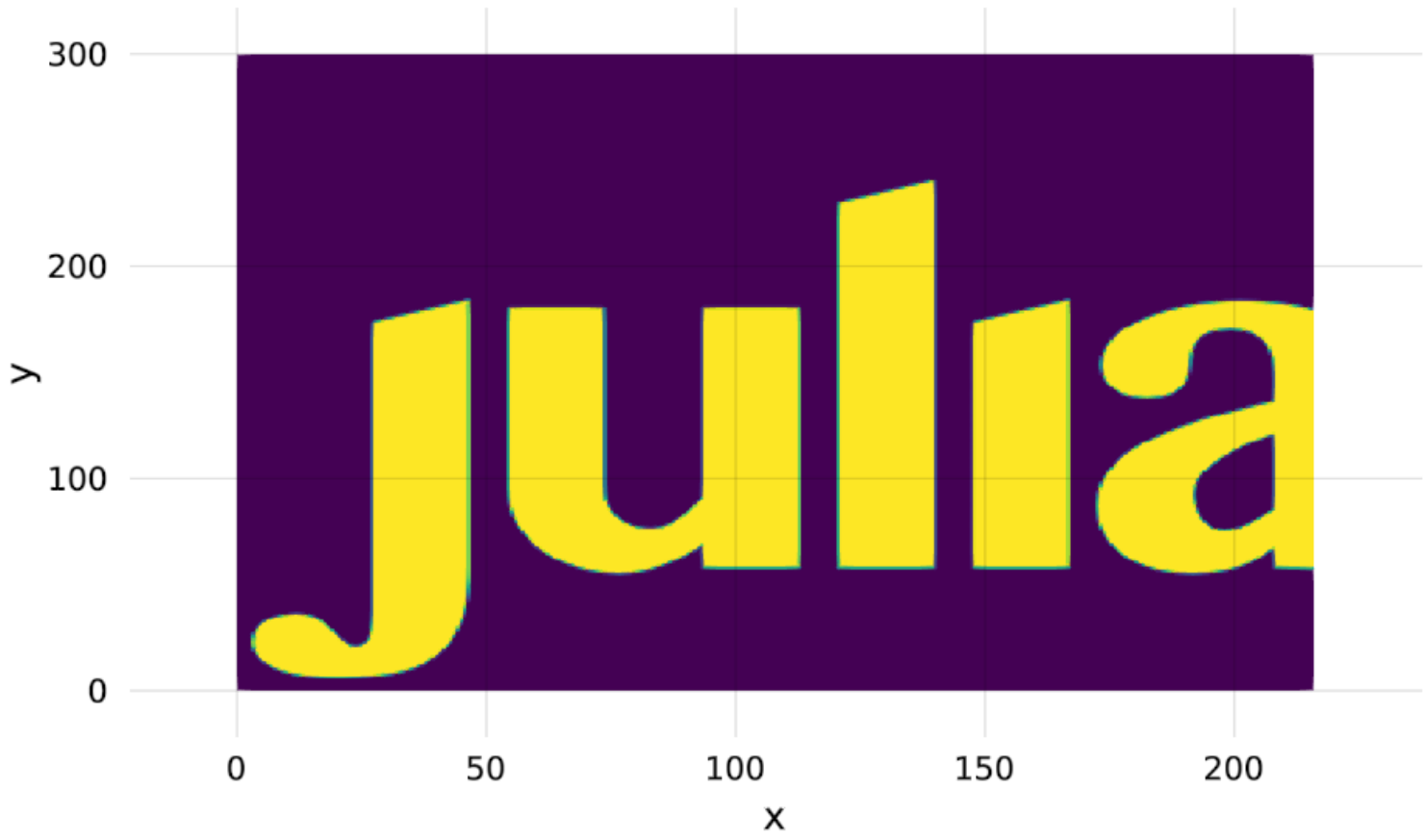
In [32]:

```
julia_array = float.(channelview(julia));
```

In [33]:

```
heatmap(julia_array[4,216:-1:1,1:300]'.+1000)
```

Out[33]:



In [34]:

```
VV=ones(300,300).*2000;
VV[40:255,1:300]=julia_array[1,1:216,1:300].*9000 .+2000;

#VVjulia_array[1,1:200,100:300].*9000 .+2000;
```

In [35]:

```
using LinearAlgebra
```

In [36]:

```
velo=VV;
nz = 300; nx = 300;
dz = 20 ; dx = 20 ;
x = (0:nx-1)*dx;
z = (0:nz-1)*dz;

V=zeros(nz+20,nx+40)
V = [repeat(velo[:,1],1,20) velo repeat(velo[:,end],1,20)];
V = [V;(repeat(V[end,:],1,20))'];

dt = 0.9*minimum(minimum(dz./velo/sqrt(2)));

vmin = minimum(velo[:,:]);
nt = Int(round(sqrt((dx*nx)^2+(dz*nz)^2)/vmin/dt+1));

t = (0:nt-1)*dt;
f = 50;
```

In [37]:

```
nt
```

Out[37]:

```
1421
```

In [38]:

```
dt
```

Out[38]:

```
0.0029886003429301236
```

In [39]:

```
ixs=160
(rw,t)=ricker(f,nz+40,dt,dt*ixs,0);
rw = rw[1:nz+20,:];

    #generate shot record
       snapshot,data2= F2d(V,rw,dx,nt,dt);
```

In [53]:

```
scene = Scene();

heat = heatmap!(scene, x,z,snapshot[end:-1:1,:,1]')[end];
N = 600
scene
record(scene, "./docs/media/animated_surface_and_wireframe.mp4",1:1:N) do i
    heat[3]=snapshot[end:-1:1,:,i]'
end
```

```
failed process: Process(`ffmpeg -loglevel quiet -i '/var/folders/f1/
rd9jgjwn3jgbfnyv0psw07480000gn/T/tmpF1BdHv/##video#371.mkv' -c:v lib
x264 -preset slow -crf 24 -pix_fmt yuv420p -c:a libvo_aacenc -b:a 12
8k -y ./docs/media/animated_surface_and_wireframe.mp4`, ProcessExite
d(1)) [1]

Stacktrace:
 [1] error(::String, ::Base.Process, ::String, ::Int64, ::String) at
./error.jl:42
 [2] pipeline_error at ./process.jl:695 [inlined]
 [3] #run#505(::Bool, ::Function, ::Cmd) at ./process.jl:653
 [4] run at ./process.jl:651 [inlined]
 [5] save(::String, ::VideoStream) at /Users/SloOoH/.julia/packages/
AbstractPlotting/tmFCk/src/display.jl:273
 [6] record(::getfield(Main, Symbol("##23#24")), ::Scene, ::String,
::StepRange{Int64,Int64}) at /Users/SloOoH/.julia/packages/AbstractP
lotting/tmFCk/src/display.jl:333
 [7] top-level scope at In[53]:6
```

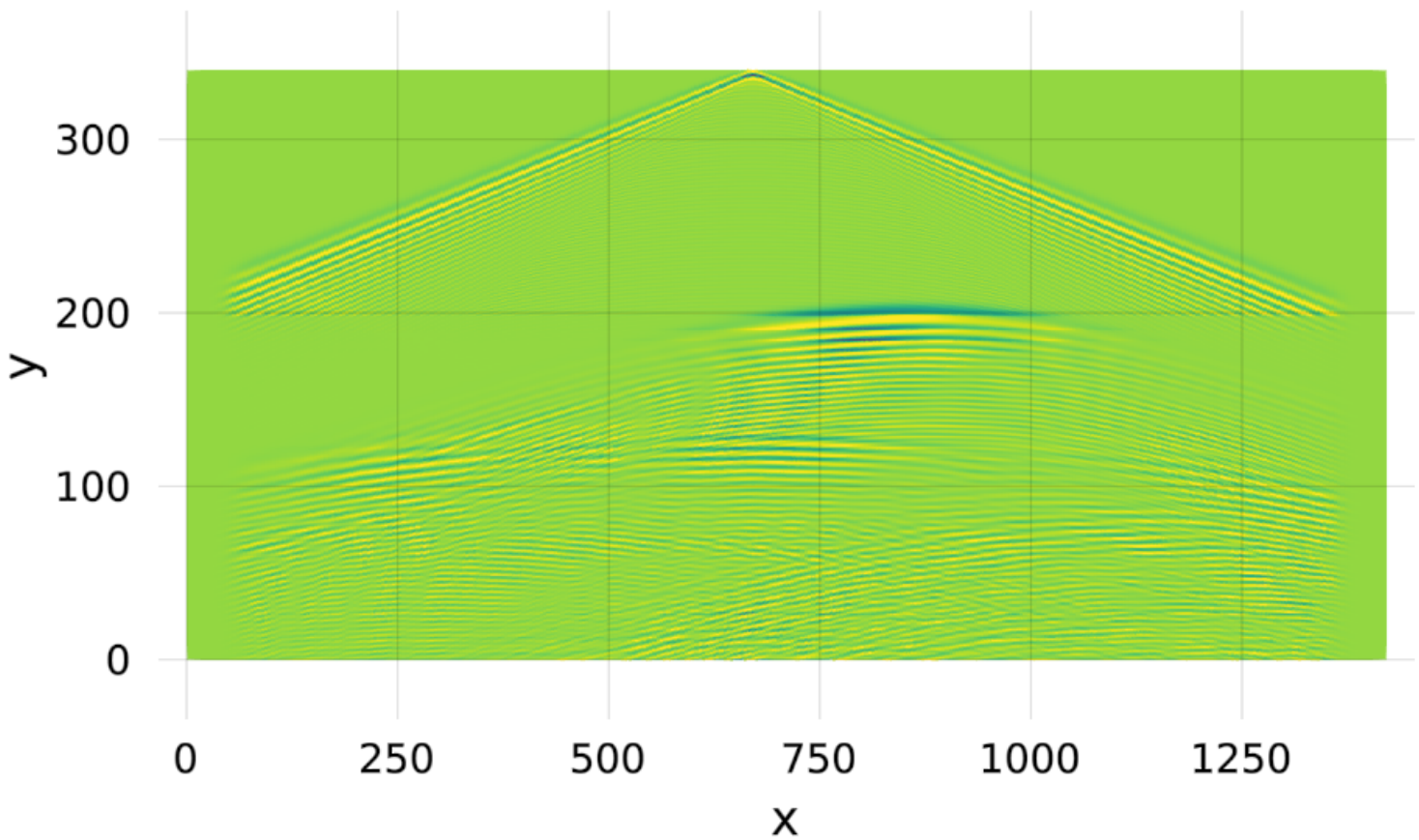
In [41]:

```
for k = 1:nt
    aux =  data2[:,k];
    amax = maximum((aux));
    data2[:,k] = data2[:,k]/amax;
   end
```

In [42]:

```
heatmap(data2[:,end:-1:1])
```

Out[42]:



In [43]:

```
velo2=VV;
nz = 300; nx = 300;
dz = 10 ; dx = 10 ;
x = (0:nx-1)*dx;
z = (0:nz-1)*dz;
#velo=zeros(nz,nx)
#velo = 2000 .*ones(nz,nx);
velo_const = 2000 .*ones(nz,nx);
#velo[151:end,1:end] = 3000*ones(50,nx);
#velo_const = 2000 .*ones(nz,nx);
V = [repeat(velo2[:,1],1,20) velo2 repeat(velo2[:,end],1,20)];
V = [V;(repeat(V[end,:],1,20))'];

Vc = [repeat(velo_const[:,1],1,20) velo_const repeat(velo_const[:,end],1,20)];
Vc = [Vc;(repeat(Vc[end,:],1,20))'];

dt = 0.9*minimum(minimum(dz./velo2/sqrt(2)));
vmin = minimum(velo2[:,:]);
nt = Int(round(sqrt((dx*nx)^2+(dz*nz)^2)/vmin/dt+1));
t = (0:nt-1)*dt;
f = 1000;
```

data = zeros(size(nt,nx)); snapshot_i = zeros(nz+20,nx+40,nt); images = zeros(nz+20,nx+40);

for ixs=1:2; data = zeros(size(nt,nx)); (rw,t) = ricker(f,nz+40,dt,dt*ixs,0); rw = rw[1:nz+20,:];

```
    (snapshot_s,data) = F2d(V,rw,dx,nt,dt);
    ( snapshot_c,data_const) = F2d(Vc,rw,dx,nt,dt);
```

end

In [44]:

```
nt
```

Out[44]:

```
1421
```

In [45]:

```
data = zeros(size(nt,nx));
snapshot_i2 = zeros(nz+20,nx+40,nt);
images2 = zeros(nz+20,nx+40);

for ixs=10:60:300;
    k=1
    data = zeros(size(nt,nx));
    (rw,t) = ricker(f,nz+40,dt,dt*ixs,0);
    rw = rw[1:nz+20,:];




    (snapshot_s,data) = F2d(V,rw,dx,nt,dt);
    ( snapshot_c,data_const) = F2d(Vc,rw,dx,nt,dt);


 data_refl = data .- data_const;


   @time    (snapshot_d,fdm) = b2d(Vc,data_refl,dx,nt,dt);


      for i = 1:nt
        snapshot_i2[:,:,i] = snapshot_c[:,:,i] .* snapshot_d[:,:,i];
    end
   i=2
for i = 2:nt
        snapshot_i2[:,:,i] = snapshot_i2[:,:,i] .+ snapshot_i2[:,:,i.-1];
    end
    images2 = images2 .+ snapshot_i2[:,:,end];


end
```

```
 14.660721 seconds (4.39 M allocations: 27.352 GiB, 22.85% gc time)
 14.581719 seconds (4.39 M allocations: 27.352 GiB, 22.69% gc time)
 14.266719 seconds (4.39 M allocations: 27.352 GiB, 22.30% gc time)
 14.367201 seconds (4.39 M allocations: 27.352 GiB, 22.61% gc time)
 14.357399 seconds (4.39 M allocations: 27.352 GiB, 22.35% gc time)
```

In [54]:

```
scene = Scene();

heat = heatmap!(scene, x,z,snapshot_i2[end:-1:1,:,1]')[end];
N = 1000
scene
record(scene, "./docs/media/animated_surface_and_wireframe.mp4",1:1:N) do i
    heat[3]=snapshot_i2[end:-1:1,:,i]'
end
```

```
failed process: Process(`ffmpeg -loglevel quiet -i '/var/folders/f1/
rd9jgjwn3jgbfnyv0psw07480000gn/T/tmpHzIJqA/##video#372.mkv' -c:v lib
x264 -preset slow -crf 24 -pix_fmt yuv420p -c:a libvo_aacenc -b:a 12
8k -y ./docs/media/animated_surface_and_wireframe.mp4`, ProcessExite
d(1)) [1]

Stacktrace:
 [1] error(::String, ::Base.Process, ::String, ::Int64, ::String) at
./error.jl:42
 [2] pipeline_error at ./process.jl:695 [inlined]
 [3] #run#505(::Bool, ::Function, ::Cmd) at ./process.jl:653
 [4] run at ./process.jl:651 [inlined]
 [5] save(::String, ::VideoStream) at /Users/Slo0oH/.julia/packages/
AbstractPlotting/tmFCk/src/display.jl:273
 [6] record(::getfield(Main, Symbol("##25#26")), ::Scene, ::String,
::StepRange{Int64,Int64}) at /Users/Slo0oH/.julia/packages/AbstractP
lotting/tmFCk/src/display.jl:333
 [7] top-level scope at In[54]:6
```

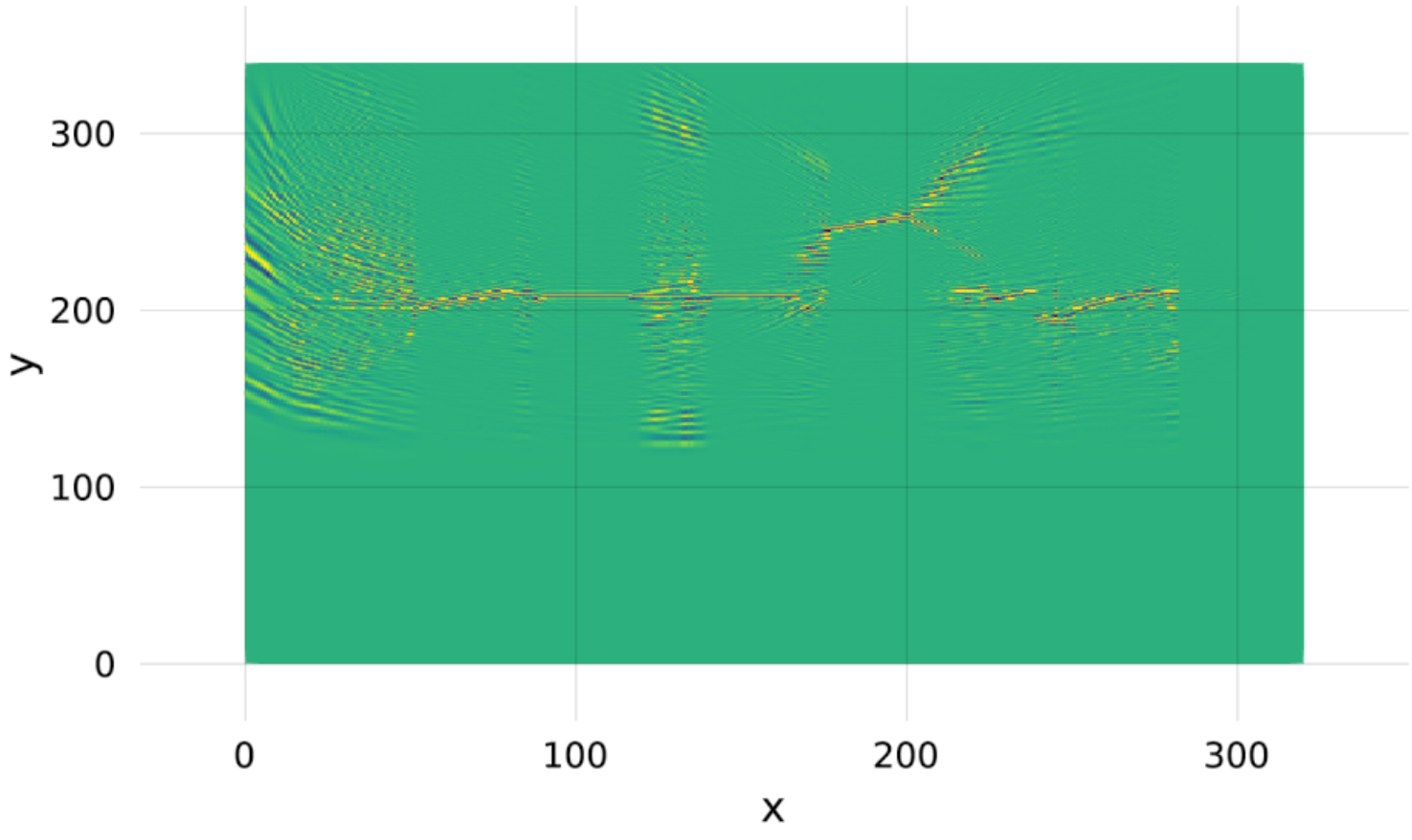
In [47]:

```
for k = 1:nx
    aux =  images2[:,k];
    amax = maximum((aux));
    images2[:,k] = images2[:,k]/amax;
   end
```

In [48]:

```
heatmap(images2[end:-1:1,:,1]')
```

Out[48]:



References

- Jones, I.F.. (2014). Tutorial: Migration imaging conditions. First Break. 32. 45-55. 10.3997/1365-2397.2014017.
- Jiang, Z, Bancroft, J, Lines, L (2010). Reverse-Timve Migration Imaging With/without Multiples. CREWES Research Report. Volume 22.