

Go to the following link

<http://www.chaos.gatech.edu/ccis2019/sc1/>

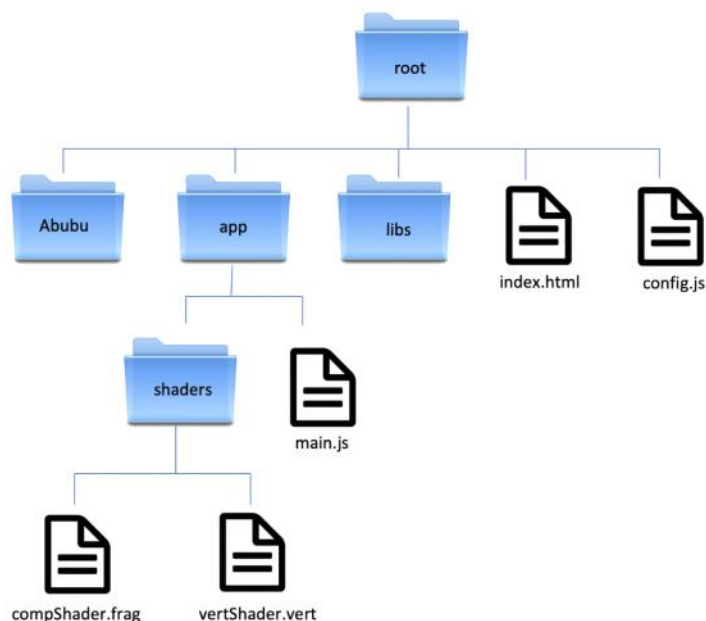
From Day 4, on the page, download the materials and the codes needed!

The objectives for today:

- Using lookup tables
- Extension to 3D simulations
- Writing data to disk
- Reduction operations
- Irregular geometries
- Random numbers

Quick reminder:

Our sample programs all have the following directory structure.



The source codes that we will be editing are mostly **main.js**, **vertShader.vert** and **compShader.frag**.

Using lookup tables

Let's look at the Beeler-Reuter [1] model again:

[1] Beeler, Go W., and H. Reuter. "Reconstruction of the action potential of ventricular myocardial fibres." The Journal of physiology 268.1 (1977): 177.

$$\begin{aligned} dy/dt &= (y_\infty - y)/\tau_y, \\ \tau_y &= 1/(\alpha_y + \beta_y), \\ y_\infty &= \alpha_y/(\alpha_y + \beta_y). \end{aligned}$$

C , defining function and values for rate constants (α or β)

$$\alpha = (C_1 \exp [C_2(V_m + C_3)] + C_4(V_m + C_5)) / (\exp [C_6(V_m + C_3)] + C_7). \quad (13)$$

Rate constant	C_1 (msec ⁻¹)	C_2 (mV ⁻¹)	C_3 (mV)	C_4 ((mV.msec) ⁻¹)	C_5 (mV)	C_6 (mV ⁻¹)	C_7
α_{s_1}	0.0005	0.083	50	0	0	0.057	1
β_{s_1}	0.0013	-0.06	20	0	0	-0.04	1
α_m	0	0	47	-1	47	-0.1	-1
β_m	40	-0.056	72	0	0	0	0
α_h	0.126	-0.25	77	0	0	0	0
β_h	1.7	0	22.5	0	0	-0.082	1
α_j	0.055	-0.25	78	0	0	-0.2	1
β_j	0.3	0	32	0	0	-0.1	1
α_d	0.095	-0.01	-5	0	0	-0.072	1
β_d	0.07	-0.017	44	0	0	0.05	1
α_t	0.012	-0.008	28	0	0	0.15	1
β_t	0.0065	-0.02	30	0	0	-0.2	1

We can define textures on the CPU side (e.g. main.js) as lookup tables of pre-calculated values:

```

645  /* function to calculate the coefficients */
646  function abCcoef(Um,C){
647      var a1 =
648          (C[0]*Math.exp(C[1]*(Um+C[2])) + C[3]*(Um+C[4]))/
649          (Math.exp(C[5]*(Um+C[2])) + C[6]);
650      return a1;
651  }
652
653  var nSamples = 512;          /* no. of samples */
654
655  var U1t = new Float32Array(nSamples);
656  var tab = new Float32Array(nSamples*4);
657
658  for(var i=0; i<nSamples; i++){
659      /* Assume params.minU1t< U1t < params.maxU1t */
660      U1t[i] = (i+0.5)*(params.maxU1t-params.minU1t)/nSamples
661              + params.minU1t;
662  }
663  /* mtht */
664  for(var i = 0; i<nSamples; i++){
665      var indx = i*4;
666      var U = U1t[i];
667
668      var a_m = abCcoef(U, ca_m);
669      var b_m = abCcoef(U, cb_m);
670      var a_h = abCcoef(U, ca_h);
671      var b_h = abCcoef(U, cb_h);
672
673      /* m_inf */
674      tab[indx] = a_m/(a_m+b_m);
675
676      /* tau_m */
677      tab[indx+1] = 1.0/(a_m+b_m);
678
679      /* h_inf */
680      tab[indx+2] = a_h/(a_h + b_h);
681
682      /* tau_h */
683      tab[indx+3] = 1.0/(a_h + b_h);
684  }
685  var mtht = new Abubu.TableTexture(tab, nSamples);
686

```

Using lookup tables - cont'd

Later, we can use the interpolating features of the textures in the shader to use the pre-calculated values of the error prone functions:

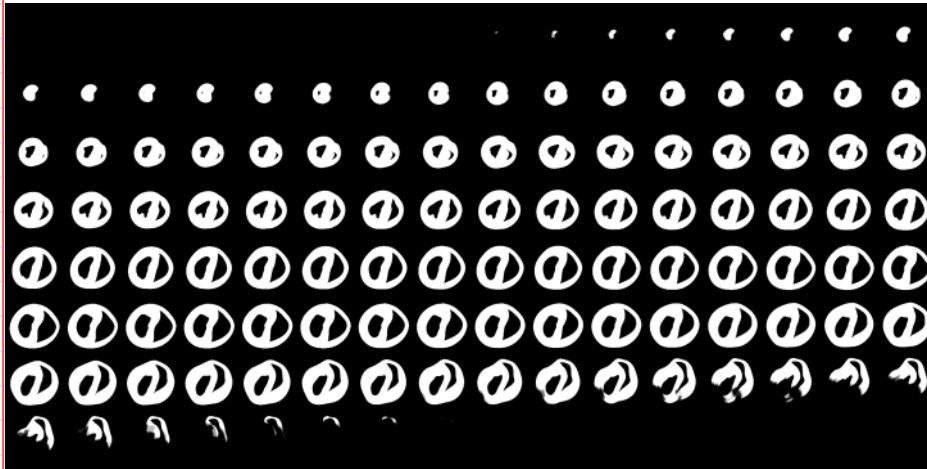
Let's look at the compShader.frag:

```
23 uniform sampler2D  mtht ;
24 uniform sampler2D  jttdt ;
25 uniform sampler2D  xtft ;
26 uniform sampler2D  ikix ;

75 float  U      = ucxfUa1.r ;
76 vec2   v      = vec2((U - minU1t)/(maxU1t - minU1t), 0.5 ) ;
77
78 vec4   mthtTab = texture( mtht, v ) ;
79 vec4   jttdtTab = texture( jttdt, v ) ;
80 vec4   xtftTab = texture( xtft, v ) ;
81 vec4   ikixTab = texture( ikix, v ) ;
82

92 float  m_inf  = mthtTab.r ;
93 float  tau_m  = mthtTab.gxC_tau_m ;
94 m = m_inf - (m_inf-m )×exp(-dt/tau_m) ;
95
```

Extension to 3D space



By stacking z-layers in a matrix structure we can start doing 3d simulations. We can also design the following function to substitute the texture function to carry out access to various locations of the matrix.

Let's have a look at the compShader.frag:

```
79 /*=====
80 * Texture3D
81 *=====
82 */
83 vec4 Texture3D( sampler2D S, vec3 texCoord )
84 {
85     vec3    texCrd = texCoord ;
86     vec3    ii = vec3(1.)/domainResolution ;
87     texCrd.x = zeroFlux(texCrd.x,ii.x) ;
88     texCrd.y = zeroFlux(texCrd.y,ii.y) ;
89     texCrd.z = zeroFlux(texCrd.z,ii.z) ;
90
91     vec4    uColor1, uColor2 ;
92     float   x, y ;
93     float   wd = mx*my - 1.0 ;
94
95     float   zSliceNo = floor( texCrd.z*mx*my ) ;
96
97     x = texCrd.x / mx ;
98     y = texCrd.y / my ;
99
100    x += (mod(zSliceNo,mx)/mx) ;
101    y += floor((wd-zSliceNo)/ mx )/my ;
102
103    return texture( S, vec2(x,y) ) ;
104 }
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130
131 /*=====
132 * Laplacian
133 *=====
134 */
135 vec3 cc = texture( crdtTxt, pixPos ).xyz ;
136 vec3 ii = vec3(1.,0.,0.)/domainResolution ;
137 vec3 jj = vec3(0.,1.,0.)/domainResolution ;
138 vec3 kk = vec3(0.,0.,1.)/domainResolution ;
139
140 float gamma = 1./3. ;
141 vec4 laplacian = (
142     Texture3D( inTrgt, cc+ii)
143     - 2.*C
144     + Texture3D( inTrgt, cc-ii) )*cdd.x
145 + (
146     Texture3D( inTrgt, cc+jj)
147     - 2.*C
148     + Texture3D( inTrgt, cc-jj) )*cdd.y
149 + (
150     Texture3D( inTrgt, cc+kk)
151     - 2.*C
152     + Texture3D( inTrgt, cc-kk) )*cdd.z ;
153
154 float dUlt2dt = laplacian.r ;
155 dUlt2dt *= diffCoeF ;
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Saving data to disk

Let's at the main.js in the OVVR model:

```
1673
1674 /*-----
1675  * recorder.probe
1676  *-----
1677 */
1678     env.rec_probe = new Abubu.Probe( env.fuuxc, { channel : 'r',
1679         probePosition : [0.5,0.5] } ) ;
1680     env.rec_recorder = new Abubu.ProbeRecorder(env.rec_probe,
1681         {
1682         sampleRate : env.rec_interval,
1683         recording: env.rec_recording ,
1684         fileName : env.rec_fileName} ) ;

2010         env.disp.updateTpt() ,
2019         env.rec_recorder.record(env.time) ;
2020         env.intervalCallor.call(env.time)

-----
1086         env.rec_recorder.save() ;
```

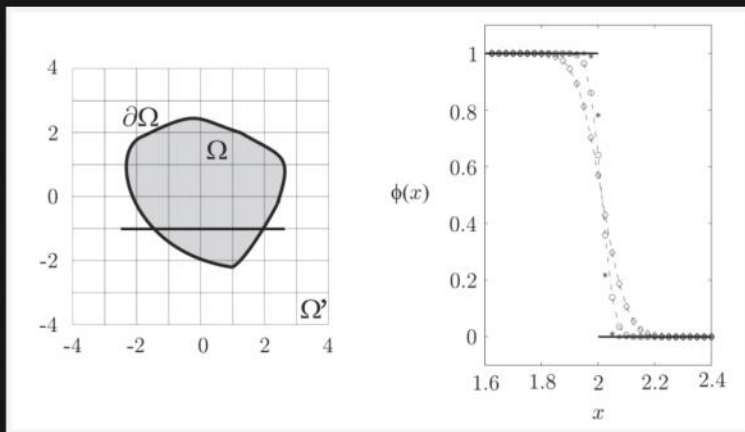
Reduction operators

Irregular geometries - Phase-Field Formulations

Fenton, Flavio H., et al. "Modeling wave propagation in realistic heart geometries using the phase-field method." *Chaos: An Interdisciplinary Journal of Nonlinear Science* 15.1 (2005): 013502.

From <https://scholar.google.com.sg/scholar?hl=en&as_sdt=0%2C11&q=fenton+phase-field&btnG=#d=gs_cit&u=%2Fscholar%3Fq%3Dinfo%3A9dqonl9agmYJ%3Ascholar.google.com%2F%26output%3Dcite%26scirp%3D0%26hl%3Den>

Fenton, Flavio H., et al. "Modeling wave propagation in realistic heart geometries using the phase-field method." *Chaos: An Interdisciplinary Journal of Nonlinear Science* 15.1 (2005): 013502.



$$\phi C_m \frac{\partial V}{\partial t} = \nabla \cdot (\phi D \nabla V) - \phi I_{ion}$$

Random numbers need distributed states over the domain

An example model that needs random numbers at each point:

Kang, Qinjun, et al. "Lattice Boltzmann model for crystal growth from supersaturated solution." *Geophysical Research Letters* 31.21 (2004).