

Test Title

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Approval

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Chapter 1

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Chapter 2

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Bibliography

- [1] H H Pennes. Analysis of tissue and arterial blood temperatures in the resting human forearm. *Journal of Applied Physiology*, 1(2):93–122, 1948.

Appendix A

Calculating the Temperature Change

```
1 function temperatureOut = tempCalcChangingMetabolismFlow(tissue,bloodT,
    airT,nt,tmax,pastCalc,start,stop,amplitudeMet,amplitudeFlow,region,
    savesteps)
2 % tempCalcChaning Metabolism How does changin metabolism affect things?
3 % tissue: holds all of the strucual information
4 % bloodT: Temperature of the blood
5 % airT: Temperature of the surrounding ait
6 % nt: Number of time steps
7 % tmax: Total amount of time the simulation should run over
8 %
9 % region: logical matrix same size as head
10 % start: units of steps
11 % stop: units of steps
12 %
13 % Written by Gregory Rothmeier (greggroth@gmail.com)
14 % Georgia State University Dept. Physics and Astronomy
15 % May, 2011
16 %#codegen
17
18 %% Default Values
19 if nargin<2, bloodT = 37; end
20 if nargin<3, airT = 24; end
21 if nargin<4, nt = 3; end
22 if nargin<5, tmax = 1; end
23 if nargin<6, pastCalc = 0; end % Voxel size (m)
24 if nargin<7, start = 10; end % in steps
25 if nargin<8, stop = 20; end % in steps
26 if nargin<9, amplitudeMet = 1.2; end % normalized
27 if nargin<10, amplitudeFlow = 1.2; end % normalized
28 if nargin<11, savesteps = 1; end
29
30
31 dx = 2*10^-3;
32 if nt<(2*tmax),
33     warning('Time step size is not large enough. Results will be
        unreliable. Consider increasing the number of steps or reducing
        tmax.')
34 end
35
```

```

36
37 % Constants used that aren't already stored in tissue
38 [xmax ymax zmax t] = size(tissue);
39 clear t;
40 dt = tmax/(nt-1);
41 % rhoBlood = 1057;
42 % wBlood = 1000;
43 % cBlood = 3600;
44
45 statusbar = waitbar(0,'Initializing');
46
47 %% Maps
48 % Creates a map that identifies where there is tissue
49 % the condition squeeze(tissue(:,:,:)~=airIndex picks out the elements
    that are
50 % tissue
51
52 temperatureOut = ones(ceil((nt-1)/savesteps),xmax,ymax,zmax,'single');
53 temperature = ones(2,xmax,ymax,zmax,'single')*airT;
54 if pastCalc == 0
55     temperature(1,squeeze(tissue(:,:,:,1))~=1) = bloodT;
56 else
57     temperature(1,:,:,:) = pastCalc(end,:,:,:);
58     % temperature(1,:,:,:) = pastCalc;
59 end
60 temperatureOut(1,:,:,:) = temperature(1,:,:,:);
61 metabMultiplier = ones([xmax ymax zmax],'single');
62 flowMultiplier = ones([xmax ymax zmax],'single');
63
64 %% Do Work.
65 % This is a vectorized version of the next section. For the love of god
66 % don't make any changes to this without first looking below to make
    sure
67 % you know what you're changing. This is [nearly] impossible to
68 % understand, so take your time and don't break it.
69 % data is stored in 'tissue' as such :
70 % [tissuetype 0 Qm c rho k w]; <-- second element is blank for all.
71 % [ 1 2 3 4 5 6 7
72
73 % This makes an array that has smoothed out variations in k by averaging
74 % all of the k's around each voxel (including itself). This is a
75 % hap-hazard solution to the problem that if you only take the value of k
76 % for the voxel without considering what surrounds it, it doesn't matter
77 % whether the head is surrounded by air, water or anything else. Since
78 % water is a better thermal conductor than air, we need a way of
79 % accounting for this. This is one way:
80 averagedk = (circshift(tissue(:,:,:,6),[1 0 0])+circshift(tissue(:,:,:,6)
    ,[-1 0 0])+circshift(tissue(:,:,:,6),[0 1 0])+circshift(tissue(:,:,:,6)
    ,[0 -1 0])+circshift(tissue(:,:,:,6),[0 0 1])+circshift(tissue(:,:,:,6)
    ,[0 0 -1])+tissue(:,:,:,6))/7;
81 rhoblood = 1057;
82 cblood = 3600;
83
84 %% Only saves every 4 steps

```

```

85 tic
86 for t2 = 1:nt-1
87     waitbar(t2/(nt-1),statusbar,sprintf('%d%%',round(t2/(nt-1)*100)));
88     if (start<t2) && (t2<stop) % for __ steps
89         metabMultiplier(region) = amplitudeMet; % region is hardcoded
90         here
91         flowMultiplier(region) = amplitudeFlow;
92     elseif t2==stop % once the period is over, reset it back to ones
93         metabMultiplier(region) = 1;
94         flowMultiplier(region) = 1;
95     end
96     temperature(2,:,:,:) = squeeze(temperature(1,:,:,:)) + ...
97         dt/(tissue(:,:,:5).*tissue(:,:,:4)).* ...
98         ((averagedk/dx^2).*...
99         (circshift(squeeze(temperature(1,:,:,:)),[1 0 0])-2*squeeze(
100             temperature(1,:,:,:))+circshift(squeeze(temperature(1,:,:,:))
101             ,[-1 0 0])+... % shift along x
102             circshift(squeeze(temperature(1,:,:,:)),[0 1 0])-2*squeeze(
103                 temperature(1,:,:,:))+circshift(squeeze(temperature(1,:,:,:))
104                 ,[0 -1 0])+... % shift along y
105                 circshift(squeeze(temperature(1,:,:,:)),[0 0 1])-2*squeeze(
106                     temperature(1,:,:,:))+circshift(squeeze(temperature(1,:,:,:))
107                     ,[0 0 -1]))... % shift along z
108                 -(1/6000)*rhoblood*flowMultiplier.*tissue(:,:,:7)*cblood.*(
109                     squeeze(temperature(1,:,:,:))-bloodT)+metabMultiplier.*
110                     tissue(:,:,:3));
111     % resets the air temperature back since it's also modified above,
112     but
113     % it needs to be kept constant throughout the calculations
114     temperature(2,squeeze(tissue(:,:,:1))==1) = airT;
115     temperatureOut(ceil(t2/savesteps),,:,:,:) = temperature(2,:,:,:);
116     temperature(1,:,:,:) = temperature(2,:,:,:); % moves 2 back to 1
117 end
118 close(statusbar);
119 toc
120 %% Keeps all of the data
121 % Note: Make sure that temperature() has enough preallocated space
122 %{
123 tic
124 for t2 = 1:nt-1
125     %tic
126     waitbar(t2/(nt-1),statusbar,sprintf('%d%%',round(t2/(nt-1)*100)));
127     if (start<t2) && (t2<stop) % for 10 steps
128         metabMultiplier(region) = amplitudeMet; % region is hardcoded
129         here
130         flowMultiplier(region) = amplitudeFlow;
131     elseif t2==stop % once the period is over, reset it back to ones
132         metabMultiplier(region) = 1;
133         flowMultiplier(region) = 1;
134     end
135     temperature(t2+1,:,:,:) = squeeze(temperature(t2,:,:,:)) + ...
136         dt/(tissue(:,:,:5).*tissue(:,:,:4)).* ...
137         ((averagedk/dx^2).*...

```

```

128     (circshift(squeeze(temperature(t2,:,:,:),[1 0 0])-2*squeeze(
        temperature(t2,:,:,:)+circshift(squeeze(temperature(t2,:,:,:),
129         ,[-1 0 0])+... % shift along x
        circshift(squeeze(temperature(t2,:,:,:),[0 1 0])-2*squeeze(
            temperature(t2,:,:,:)+circshift(squeeze(temperature(t2,:,:,:),
130                ),[0 -1 0])+... % shift along y
            circshift(squeeze(temperature(t2,:,:,:),[0 0 1])-2*squeeze(
                temperature(t2,:,:,:)+circshift(squeeze(temperature(t2,:,:,:),
131                    ),[0 0 -1]))... % shift along z
                -(1/6000)*rhoblood*flowMultiplier.*tissue(:,:,:7)*cblood.*(
                    squeeze(temperature(t2,:,:,:))-bloodT)+metabMultiplier.*
                    tissue(:,:,:3));
132     % resets the air temperature back since it's also modified above,
        but
133     % it needs to be kept constant throughout the calculations
134     temperature(t2+1,squeeze(tissue(:,:,:1))==1) = airT;
135     %dispTimeLeft(1,1,nt-1,t2)
136 end
137 close(statusbar);
138 toc
139 %}
140
141 %% Old Code
142 % This is what used to be used. It's much slower (~60 times slower), but
143 % it's much easier to understand compared to the above code. If any
144 % changes need to be made above, first look through this code to ensure
145 % you understand what's happening before making changes. It's really
        easy
146 % to mess up the code above and nearly impossible to figure out where.
147
148 % good luck.
149
150
151 %{
152 for t2 = 1:nt-1
153     for x2 = 2:xmax-1
154         for y2 = 2:ymax-1
155             for z2 = 2:zmax-1
156                 if tissue(x2,y2,z2,1) ~= 1,
157                     temperature(t2+1,x2,y2,z2) = temperature(t2,x2,y2,z2)
                        + (dt/(tissue(x2,y2,z2,5)*tissue(x2,y2,z2,4)))*((
                            tissue(x2,y2,z2,6)/dx^2)*...
158                     (temperature(t2,x2+1,y2,z2)-2*temperature(t2,x2,y2,
                            z2)+temperature(t2,x2-1,y2,z2))+...
159                     temperature(t2,x2,y2+1,z2)-2*temperature(t2,x2,y2,z2
                            )+temperature(t2,x2,y2-1,z2))+...
160                     temperature(t2,x2,y2,z2+1)-2*temperature(t2,x2,y2,z2
                            )+temperature(t2,x2,y2,z2-1))...
161                     -(1/6000)*rhoBlood*wBlood*cBlood*(temperature(t2,x2,
                            y2,z2)-bloodT)+tissue(x2,y2,z2,3));
162                 end
163             end
164         end
165     end

```

```
166  end
167  %}
168
169
170  end
```

Appendix B

Calculating The Equilibrium Temperature