Middle Intestine:

```
globals
[
  g-Mucous-Patch
  g-Mucous-Height
  g-Lumen-Color
  g-Cell-Height
  g-Cell-Patch
  g-Cell-List-Num
  g-HSpeed-In-Lumen
  g-HSpeed-In-Mucous

  g-Brownian-Speed-In-Lumen
  g-Brownian-Speed-In-Mucous
  g-Bottom-Mucous-Top-Y
  g-Bottom-Mucous-Bottom-Y
  g-Top-Mucous-Top-Y
  g-Top-Mucous-Bottom-Y
  g-End-Pharynx
  g-Pharynx-Y

  g-Seed

]

breed [ yeast a-yeast ]                ;creates yeast turtle breed
breed [ Benefical-Microbe a-probiotic ]        ;creates Benefical-Microbe turtle breed


patches-own [Patch-Type              ;creates the variable Patch-Type-- can be mucous, lumen, or
cell

p-Yeast-biofilm                ;creates the variables for Benefical-Microbel molecule
concentrations as well as both biofilm levels
p-Benefical-Microbe-molecule-concentration
p-Benefical-Microbe-biofilm
]
```

Yeast-own [Yeast-adhesion   ;creates variables for yeast adhesion (unstuck, stuck, and
biofilm) and tracks how long a yeast is stuck
Yeast-time-stuck   ;to then become a biofilm
]

Benefical-Microbe-own [Benefical-Microbe-adhesion   ;creates variables for
Benefical-Microbe adhesion (unstuck, stuck, and biofilm) and tracks how long a bacterium is
stuck
Benefical-Microbe-time-stuck   ;to then become a biofilm
]

                    ;Setup and Go procedures

to setup   ;setup procedure
  clear-all   ;resets model and calls on the following setup procedures
  setup-globals   ;globals, cells, muscous, & lumen
  setup-cells
  setup-Mucous
  setup-Lumen

  ifelse seed-on   ; if the seed-on switch is set, use the number in the g-input-seed
box to start the simulation
    [set g-Seed g-input-seed]
    [set g-Seed new-seed]   ; otherwise, start with a random seed
  random-seed g-Seed
  set g-input-seed g-Seed
  reset-ticks
end

to go   ;go procedure
  tick   ;advances and updates model with each tick
  Worm-Eat   ;calls the procedures which simulate worm eating and
Benefical-Microbe molecule secretion
  Benefical-Microbe-Secrete

```
  ask yeast [(  ifelse
    Yeast-adhesion = "unstuck" [free-yeast]              ;if Yeast are unstuck then the free-yeast
procedure is called
    Yeast-adhesion = "stuck" [stuck-yeast]               ;if Yeast are stuck then the stuck-yeast
procedure is called
    Yeast-adhesion = "biofilm" [Biofilm-Yeast]            ;If Yeast are biofilm then the
biofilm-yeast procedure is called
  )]



  ask Benefical-Microbe [(  ifelse
    Benefical-Microbe-adhesion = "unstuck" [Free-Benefical-Microbe]              ;if
Benefical-Microbe are unstuck then the free-Benefical-Microbe procedure is called
    Benefical-Microbe-adhesion = "stuck" [Stuck-Benefical-Microbe]              ;if
Benefical-Microbe are stuck then the stuck-Benefical-Microbe procedure is called
    Benefical-Microbe-adhesion = "biofilm" [Biofilm-Benefical-Microbe]              ;If
Benefical-Microbe are biofil then the biofilm-Benefical-Microbe procedure is called
  )]



  ask patches [ if p-Benefical-Microbe-molecule-concentration > 0 [
      set p-Benefical-Microbe-molecule-concentration
(p-Benefical-Microbe-molecule-concentration - Benefical-Microbe-molecule-degradation-rate) ]
]   ;patches degrade Benefical-Microbel molecule at a set rate if the concentration is above 0

  ask patches [ if Patch-type = "Lumen" [
   (ifelse
     show-conc-of = "SM" [
       set pcolor scale-color pink p-Benefical-Microbe-molecule-concentration 1000 0 ]
     show-conc-of = "yeast-biofilm" [
       set pcolor scale-color green p-Yeast-biofilm 150 0]
   )
   ] ] ;lumen patches change color on a gradient with Benefical-Microbel molecule levels
  if g-End-Pharynx <= 20 [
  ask patch g-End-Pharynx abs g-Pharynx-Y [if (count yeast-here with [color = yellow] >= 1)
[ask patch g-End-Pharynx (g-Pharynx-Y + 1) [set Patch-Type "Lumen"]]]
```

```
    ask patch g-End-Pharynx abs g-Pharynx-Y [if (count yeast-here with [color = yellow] >= 1)
[ask patch g-End-Pharynx (g-Pharynx-Y  + 2) [set Patch-Type "Mucous" set pcolor green]]]
    ask patch g-End-Pharynx g-Pharynx-Y [if (count yeast-here with [color = yellow] >= 1) [ask
patch g-End-Pharynx (g-Pharynx-Y - 1) [set Patch-Type "Lumen"]]]
    ask patch g-End-Pharynx g-Pharynx-Y [if (count yeast-here with [color = yellow] >= 1) [ask
patch g-End-Pharynx (g-Pharynx-Y - 2) [set Patch-Type "Mucous" set pcolor green set
g-End-Pharynx g-End-Pharynx + 1]]]
  ]
  if g-End-Pharynx > 20[
    set g-End-Pharynx -18.5
    set g-Pharynx-Y g-Pharynx-Y - 1 ]
  ;if any? yeast with [color = red and xcor = min-pxcor] [user-message "The worm has died"
stop]            ;worm dies if biofilm yeast block its mouth and it can no longer eat
   let x random-between 0 100000
    if x < Worm-Death-Probability +  (count yeast with [color = red]) [user-message "The worm
has died" stop]  ;worm dies at a random probability set by the appropriate slider and is influneced
by the number of biofilm yeast


end
```


                    ;Procedures called during Setup


```
to setup-globals                    ;globals setup procedure
  set  g-Mucous-Height 0.5                ;assigns fixed values to all global varibales & shapes to
turtle breeds
  set  g-Cell-Height 9                ;assigns the x and y cor of the mucous patch layers

  set g-HSpeed-In-Lumen 0.1
  set g-HSpeed-In-Mucous 0.0
  set g-Brownian-Speed-In-Lumen .1
  set g-Brownian-Speed-In-Mucous .1
  set-default-shape yeast "circle"
  set-default-shape Benefical-Microbe "circle"
  set g-End-Pharynx -19
```

```
  set g-Pharynx-Y 0

  set g-Bottom-Mucous-Bottom-Y min-pycor + g-Cell-Height
  set g-Bottom-Mucous-Top-Y min-pycor + g-Cell-Height + g-Mucous-Height
  set g-Top-Mucous-Bottom-Y max-pycor  -  g-Cell-Height - g-Mucous-Height
  set g-Top-Mucous-Top-Y max-pycor - g-Cell-Height

end

;12microns = 4 yeast cells tall (funnel opening)
;6 microns = 2 yeast cells (funnel depth)

to setup-Mucous                    ;mucous setup procedure
set g-Mucous-Patch patches with          ;sets color & patch type of the mucous layer which is
defined with using global variables
  [ (pycor >= g-Bottom-Mucous-Bottom-Y and pycor <= g-Bottom-Mucous-Top-Y )
     or
    (pycor >= g-Top-Mucous-Bottom-Y and pycor  <= g-Top-Mucous-Top-Y )
    ]
  ask g-Mucous-Patch [
    set pcolor 56
    set Patch-Type "Mucous"
]
  ask patch -20 2 [
   set pcolor 56
   set Patch-Type "Mucous"
  ]
 ask patch -20 -2 [
   set pcolor 56
    set Patch-Type "Mucous" ]
end



to setup-Lumen                  ;lumen setup procedure
  ask patches [                   ;defines the lumen to be patches between the mucous layers &
assigns color
   if (Patch-Type != "Mucous" and pycor >  g-Bottom-Mucous-Top-Y and pycor <
g-Top-Mucous-Bottom-Y )
      [ set Patch-Type "Lumen" set pcolor white]
```

```
                              ;sets values for Benefical-Microbel and yeast molecule/biofilm levels
at 0
    set p-Benefical-Microbe-molecule-concentration 0
    set p-Yeast-biofilm 0
    set p-Benefical-Microbe-biofilm 0
  ]
  ask patch -20 1 [
    set pcolor white
    set Patch-Type "Lumen"
  ]
  ask patch -20 -1 [
    set pcolor white
    set Patch-Type "Lumen"
  ]
end




to setup-cells                                ;epithelial cell setup procedure
  set g-Cell-Patch patches with [Patch-Type != "Mucous" and Patch-Type != "Lumen"]
  ask g-Cell-Patch [                              ;defines epithelial cells as any patch not set as
mucous or lumen & sets color
    set pcolor 98
    set Patch-Type "Cell"
  ]
end




                    ;Procedures called while the worm Eats




to Worm-Eat
  if (Eat) [                                  ;simulates C. elegans eating by creating 1 yeast/1
Benefical-Microbe a determined probability
    if not any? yeast with [xcor = min-pxcor] [              ;worm can only eat a yeast if there is
not one already there
```

```
      create-1-yeast Yeast-intake-prob  min-pxcor min-pxcor  0 0        ;probability value assigned
by appropriate sliders
    ]
      create-1-Benefical-Microbe Benefical-Microbe-intake-prob   min-pxcor min-pxcor
g-Bottom-Mucous-Top-Y g-Top-Mucous-Bottom-Y    ]
end




to random-position [#xmin #xmax #ymin #ymax]                ;random-position procedure
  setxy (random-between #xmin #xmax) ( random-between #ymin #ymax)    ;sets x and y cor to
random values bewteen the assigned max and min of x and y
end




to create-1-yeast  [#prob  #min-x #max-x #min-y #max-y]        ;procedure to create yeast
  if ((random-between 0 100) <= #prob) [                ;creates yeast if a random value chosen
is less than or equal to the set yeast intake probability
      create-yeast 1 [
        random-position #min-x #max-x #min-y #max-y          ;calls random position procedure
          set color  blue                          ;sets yeast color and size
          set size .9
          set heading 90                          ;need to be heading down lumen so see yeast in
front of them
      set Yeast-adhesion "unstuck"                    ;sets yeast as unstuck and time stuck at 0
      set Yeast-time-stuck 0
    ]
        ]
end




to create-1-Benefical-Microbe [#prob #min-x #max-x #min-y #max-y]         ;procedure to create
Benefical-Microbe
  if ((random-between 0 100) <= #prob)[                ;creates Benefical-Microbe if a random
value chosen is less than or equal to the set Benefical-Microbe intake probability
        create-Benefical-Microbe 1 [
      random-position #min-x #max-x #min-y #max-y          ;calls random position procedure
        set heading 90                          ;sets Benefical-Microbe direction
```

```
        set color 23                           ;sets Benefical-Microbe color and size
        set size .9
    set Benefical-Microbe-adhesion "unstuck"                  ;sets Benefical-Microbe as
unstuck and time stuck at 0
    set Benefical-Microbe-time-stuck 0
    ]
          ]
end
```

;Yeast Procedures

```
to free-yeast                                 ;Free yeast procedure -- already within an
'ask yeast' statement LIZ

  if (Patch-Type = "Lumen" and ( xcor >= (max-pxcor - 0.2) and xcor <= max-pxcor)) [die]
;keeps yeast within the lumen
  let yeast-ahead one-of other yeast in-cone 1 100          ; need to look whether yeast in
front of them -- could be on same patch

  if yeast-ahead = nobody [move-yeast]                      ;if no yeast on patch ahead call
move procedure

  if yeast-ahead != nobody [                               ;Yeast have a chance of slipping by other
yeast in their way
    let x random-between 0 100
    if x < (Yeast-slip-prob - p-Yeast-biofilm ) [move-yeast]
  ]


  let x random-between 0 100        ;yeast stick if a randomly chosen value is less than the
assigned yeast adhesion probability
  if x < (Yeast-adhesion-prob - p-Benefical-Microbe-molecule-concentration + p-Yeast-biofilm ) [
```

```
    set Yeast-adhesion "stuck"                    ;sets the yeast's state as stuck
    set color yellow
    ]

end




to stuck-yeast                              ;stuck yeast procedure

  set Yeast-time-stuck (Yeast-time-stuck + 1)         ;increases the yeast time stuck
  let nearby-stuck-yeast other yeast in-radius Yeast-biofilm-radius with [Yeast-time-stuck >=
Yeast-biofilm-time-threshold]  ; check to see if there are any other
                                                      ; yeast nearby that have been stuck
a while

  let nearby-unstuck-yeast other yeast in-radius 0.9
  if any? nearby-stuck-yeast
    [let x random-between 0 100
      if x < Yeast-deadhesion-Prob [
        set Yeast-adhesion "unstuck"
        set color blue
        set Yeast-time-stuck 0]
    ]

   ifelse           ;if yeast have been stuck as long as the set threshold and nearby yeast are stuck
they become biofilm
  (Yeast-time-stuck >= Yeast-biofilm-time-threshold) and any? nearby-stuck-yeast
    [set color red  set Yeast-adhesion "biofilm"]

    [ let x random-between 0 100      ; if no yeast stuck nearby, see if should become unstuck
      if x < Yeast-deadhesion-Prob [
        set Yeast-adhesion "unstuck"                 ;sets the yeast's state as unstuck, resets the
yeast's time stuck
        set color blue
        set Yeast-time-stuck 0 ]
    ]



end
```

```
to Biofilm-Yeast                                    ;yeast biofilm procedure
 set p-Yeast-biofilm (p-Yeast-biofilm + Yeast-biofilm-secretion-rate) ;increases the biofilm value
by the set secretion rate
end




to move-yeast                                  ;move yeast procedure
   if (Patch-Type = "Mucous") [                       ;if yeast are in the mucous set heading to a
random direction
      if (ycor >= (g-Bottom-Mucous-Top-Y ) and ycor <= (g-Top-Mucous-Bottom-Y ) )
       [ set heading random-between 0 360
          forward g-Brownian-Speed-In-Mucous              ;move forward by determined global
variable value
          setxy xcor + g-HSpeed-In-Mucous  ycor ]]        ;set x and y to current x & current y +
defined global vairable
  let yeast-ahead one-of other yeast in-cone 1 100
   if (Patch-Type = "Lumen") [                          ;if yeast in the lumen set the heading to 90
degrees and move forward by yeast speed
   if (xcor >= -21 and xcor <= g-End-Pharynx - 2)[
      set heading 45
     setxy xcor random-between 1 -1]
   if (xcor >= g-End-Pharynx - 1.5)[
     set heading -45 + random 90
     setxy xcor 0]
   if yeast-ahead != nobody [
   let x random-between 0 100
   if x < (Yeast-bounce-prob) [set Yeast-speed (Yeast-speed * 0.5)]
 ]
     set heading 45 + random 90
     setxy xcor + Yeast-Speed ycor]
     ;fd Yeast-Speed  ]
 if (xcor > 20) [die]


   if (Patch-Type = "Cell") [ setxy xcor ycor ]           ;if yeast in epithelial cells set x and y to
current x and y cor
```

end

to-report random-between [#min #max]   ;report procedure for random-between
  report #min + random-float (#max - #min)   ;reports a value equal to the min + a
randomly chosen vaule greater than or equal to 0 but less than (max-min)
end

                              ;Benefical-Microbe Procedures

to Free-Benefical-Microbe   ;Free Benefical-Microbe procedure
                              ;keeps Benefical-Microbe within the lumen
  if (Patch-Type = "Lumen" and (xcor >= (max-pxcor - 0.2) and xcor <= max-pxcor)) [die]

  Move-Benefical-Microbe   ;calls move-Benefical-Microbe procedure
and the stick Benefical-Microbe procedure

                              ;Benefical-Microbe stick if a randomly chosen value is less than
the assigned yeast adhesion probability
  let x random-between 0 100
  if x < (Benefical-Microbe-adhesion-prob + p-Benefical-Microbe-biofilm) [
  set Benefical-Microbe-adhesion "stuck"   ;sets bacterium state to stuck
  ]

end

to Stuck-Benefical-Microbe   ;Stuck Benefical-Microbe procedure

```
    set Benefical-Microbe-time-stuck (Benefical-Microbe-time-stuck + 1)          ;increases the
Benefical-Microbe time stuck

    ifelse                             ;if yeast have been stuck as long as the set threshold they
become biofilm & they try to become unstuck if not
     (Benefical-Microbe-time-stuck >= Benefical-Microbe-biofilm-time-threshold) [set
Benefical-Microbe-adhesion "biofilm"]

    [ let x random-between 0 100                    ;Benefical-Microbe randomly unstick if a
chosen value is below the Yeast deadhesion probability
     if x < Benefical-Microbe-deadhesion-Prob [
       set Benefical-Microbe-adhesion "unstuck"              ;sets bacterium state as unstuck
and resets their time stuck counter
       set Benefical-Microbe-time-stuck 0
   ]
   ]
  end




to Biofilm-Benefical-Microbe                                ;Benefical-Microbel biofilm
procedure
   set p-Benefical-Microbe-biofilm (p-Benefical-Microbe-biofilm +
Benefical-Microbe-biofilm-secretion-rate) ;increases their biofilm value by the set secretion rate
  end




to Move-Benefical-Microbe                              ;move Benefical-Microbe procedure
     if (Patch-Type = "Mucous") [                  ;if Benefical-Microbe are in the mucous set
heading to a random direction
          if (xcor < -16 and xcor > -15) [
       if (ycor >= (g-Bottom-Mucous-Bottom-Y ) and ycor <= (g-Top-Mucous-Top-Y ) )
       [ set heading random-between 0 360
          forward g-Brownian-Speed-In-Mucous                ;move forward by determined global
variable value
        setxy xcor + g-HSpeed-In-Mucous  ycor ]] ]        ;set x and y to current x & current y +
defined global vairable
     if (Patch-Type = "Lumen") [                         ;if yeast in the lumen set the heading to 90
degrees and move forward by yeast speed
```

```
      if (xcor >= -17 and xcor <= g-End-Pharynx - 2)[
        set heading 45
       setxy xcor random-between 1 -1]
      if (xcor >= g-End-Pharynx - 1.5)[
        set heading -45 + random 90
        setxy xcor 0]
      set heading 45 + random 90
        setxy xcor + Benefical-Microbe-Speed ycor]
  ;   fd Benefical-Microbe-Speed ]                    ;set x and y to current x & current y + defined
global vairable


      if (Patch-Type = "Cell") [setxy xcor ycor]          ;if Benefical-Microbe in epithelial cells set
x and y to current x and y cor

    end



to Benefical-Microbe-Secrete              ;Benefical-Microbe secretion procedure
  ask Benefical-Microbe [               ;Benefical-Microbe secrete their molecule at X rate which
adds to that patch's concentration
    set p-Benefical-Microbe-molecule-concentration
(p-Benefical-Microbe-molecule-concentration + Benefical-Microbe-molecule-secretion-rate)
  ]
End
```

Anterior Intestine Model

```
globals
[
  g-Mucous-Patch
  g-Mucous-Height
  g-Lumen-Color
  g-Cell-Height
  g-Cell-Patch
  g-Cell-List-Num
  g-HSpeed-In-Lumen
  g-HSpeed-In-Mucous

  g-Brownian-Speed-In-Lumen
```

```
    g-Brownian-Speed-In-Mucous
    g-Bottom-Mucous-Top-Y
    g-Bottom-Mucous-Bottom-Y
    g-Top-Mucous-Top-Y
    g-Top-Mucous-Bottom-Y
    g-End-Pharynx
    g-Pharynx-Y

    g-Seed

]

breed [ yeast a-yeast ]              ;creates yeast turtle breed
breed [ Bacteria a-probiotic ]         ;creates Bacteria turtle breed



patches-own [Patch-Type              ;creates the variable Patch-Type-- can be mucous, lumen, or
cell
p-Yeast-biofilm                 ;creates the variables for bacterial molecule concentrations as
well as both biofilm levels
p-Bacteria-molecule-concentration
p-Bacteria-biofilm
]

Yeast-own [Yeast-adhesion            ;creates variables for yeast adhesion (unstuck, stuck, and
biofilm) and tracks how long a yeast is stuck
Yeast-time-stuck                ;to then become a biofilm
]

Bacteria-own [Bacteria-adhesion        ;creates variables for bacteria adhesion (unstuck, stuck,
and biofilm) and tracks how long a bacterium is stuck
Bacteria-time-stuck              ;to then become a biofilm
]




                   ;Setup and Go procedures
```

```
to setup                      ;setup procedure
  clear-all                   ;resets model and calls on the following setup procedures
  setup-globals               ;globals, cells, muscous, & lumen
  setup-cells
  setup-Mucous
  setup-Lumen

  ifelse seed-on              ; if the seed-on switch is set, use the number in the g-input-seed
box to start the simulation
    [set g-Seed g-input-seed]
    [set g-Seed new-seed]              ; otherwise, start with a random seed
  random-seed g-Seed
  set g-input-seed g-Seed
  reset-ticks
end




to go                        ;go procedure
  tick                        ;advances and updates model with each tick
  Worm-Eat                    ;calls the procedures which simulate worm eating and bacteria
molecule secretion
  Bacteria-Secrete

  ask yeast [(  ifelse
    Yeast-adhesion = "unstuck" [free-yeast]            ;if Yeast are unstuck then the free-yeast
procedure is called
    Yeast-adhesion = "stuck" [stuck-yeast]            ;if Yeast are stuck then the stuck-yeast
procedure is called
    Yeast-adhesion = "biofilm" [Biofilm-Yeast]            ;If Yeast are biofilm then the
biofilm-yeast procedure is called
    )]




  ask bacteria [(  ifelse
    Bacteria-adhesion = "unstuck" [Free-bacteria]            ;if bacteria are unstuck then the
free-bacteria procedure is called
    Bacteria-adhesion = "stuck" [Stuck-bacteria]            ;if bacteria are stuck then the
stuck-bacteria procedure is called
```

```
    Bacteria-adhesion = "biofilm" [Biofilm-bacteria]              ;If bacteria are biofil then the
biofilm-bacteria procedure is called
  )]




  ask patches [ if p-Bacteria-molecule-concentration > 0 [
      set p-Bacteria-molecule-concentration (p-Bacteria-molecule-concentration -
Bacteria-molecule-degradation-rate) ] ]    ;patches degrade Bacterial molecule at a set rate if the
concentration is above 0

  ask patches [ if Patch-type = "Lumen" [
  (ifelse
    show-conc-of = "SM" [
      set pcolor scale-color pink p-Bacteria-molecule-concentration 1000 0 ]
    show-conc-of = "yeast-biofilm" [
      set pcolor scale-color green p-Yeast-biofilm 150 0]
  )
  ] ] ;lumen patches change color on a gradient with bacterial molecule levels
  if g-End-Pharynx <= 20 [
  ask patch g-End-Pharynx abs g-Pharynx-Y [if (count turtles-here  >= 3) [ask patch
g-End-Pharynx (g-Pharynx-Y + 1) [set Patch-Type "Lumen"]]]
  ask patch g-End-Pharynx abs g-Pharynx-Y [if (count turtles-here  >= 3) [ask patch
g-End-Pharynx (g-Pharynx-Y  + 2) [set Patch-Type "Mucous" set pcolor green]]]
  ask patch g-End-Pharynx g-Pharynx-Y [if (count turtles-here  >= 3) [ask patch g-End-Pharynx
(g-Pharynx-Y - 1) [set Patch-Type "Lumen"]]]
  ask patch g-End-Pharynx g-Pharynx-Y [if (count turtles-here  >= 3) [ask patch g-End-Pharynx
(g-Pharynx-Y - 2) [set Patch-Type "Mucous" set pcolor green set g-End-Pharynx g-End-Pharynx
+ 1]]]
  ;if g-End-Pharynx > -10 [set g-End-Pharynx -14 set g-Pharynx-Y g-Pharynx-Y - 1]
  ]
    if any? yeast with [color = red and xcor = min-pxcor] [user-message "The worm has died"
stop]              ;worm dies if biofilm yeast block its mouth and it can no longer eat
   let x random-between 0 1000
   if x < Worm-Death-Probability +  (count yeast with [color = red]) [user-message "The worm
has died" stop]  ;worm dies at a random probability set by the appropriate slider and is influneced
by the number of biofilm yeast

end
```

;Procedures called during Setup


```
to setup-globals                    ;globals setup procedure
  set  g-Mucous-Height .5              ;assigns fixed values to all global varibales & shapes to
turtle breeds
  set  g-Cell-Height 9                ;assigns the x and y cor of the mucous patch layers

  set g-HSpeed-In-Lumen 0.1
  set g-HSpeed-In-Mucous 0.0
  set g-Brownian-Speed-In-Lumen .1
  set g-Brownian-Speed-In-Mucous .1
  set-default-shape yeast "circle"
  set-default-shape Bacteria "circle"
  set g-End-Pharynx -14
  set g-Pharynx-Y 0

  set g-Bottom-Mucous-Bottom-Y min-pycor + g-Cell-Height
  set g-Bottom-Mucous-Top-Y min-pycor + g-Cell-Height + g-Mucous-Height
  set g-Top-Mucous-Bottom-Y max-pycor  -  g-Cell-Height - g-Mucous-Height
  set  g-Top-Mucous-Top-Y max-pycor - g-Cell-Height

end



to setup-Mucous                   ;mucous setup procedure
set g-Mucous-Patch patches with         ;sets color & patch type of the mucous layer which is
defined with using global variables
  [ (pycor >= g-Bottom-Mucous-Bottom-Y and pycor <= g-Bottom-Mucous-Top-Y )
     or
    (pycor >= g-Top-Mucous-Bottom-Y and pycor  <= g-Top-Mucous-Top-Y )
   ]
  ask patches with [
  pxcor = -16 and pycor >= -3
```

```
  or
pxcor = (pycor - 13) and pycor <= -1 and pycor >= -3
  ;or
;abs pxcor = (pycor - 13) and pycor >= 1 and pycor <= 3
]
  [
set pcolor green
set Patch-Type "Mucous"
]
ask patches with [
pxcor = -16 and pycor <= 3
  or
abs pxcor = (pycor + 13) and pycor >= 1 and pycor <= 3 and pxcor < 0
]
[
set pcolor green
set Patch-Type "Mucous"
]
ask g-Mucous-Patch [
  set pcolor 56
  set Patch-Type "Mucous"
]
end



to setup-Lumen;lumen setup procedure
  ask patches with [
   pxcor = -15 and pycor = 1]
    [ set Patch-Type "Lumen" set pcolor white]
  ask patches with [
   pxcor = -15 and pycor = -1]
    [ set Patch-Type "Lumen" set pcolor white]
  ask patches with [
   pxcor = -16 and pycor = 1]
    [ set Patch-Type "Lumen" set pcolor white]
  ask patches with [
   pxcor = -16 and pycor = -1]
    [ set Patch-Type "Lumen" set pcolor white]
```

```
  ask patches [                        ;defines the lumen to be patches between the mucous layers &
assigns color
    if (Patch-Type != "Mucous" and pycor >  g-Bottom-Mucous-Top-Y and pycor <
g-Top-Mucous-Bottom-Y )
      [ set Patch-Type "Lumen" set pcolor white]


                        ;sets values for bacterial and yeast molecule/biofilm levels at 0
    set p-Bacteria-molecule-concentration 0
    set p-Yeast-biofilm 0
    set p-Bacteria-biofilm 0
  ]
end




to setup-cells                            ;epithelial cell setup procedure
  set g-Cell-Patch patches with [Patch-Type != "Mucous" and Patch-Type != "Lumen"]
  ask g-Cell-Patch [                        ;defines epithelial cells as any patch not set as
mucous or lumen & sets color
    set pcolor 98
    set Patch-Type "Cell"
  ]
end




                        ;Procedures called while the worm Eats



to Worm-Eat
  if (Eat) [                            ;simulates C. elegans eating by creating 1 yeast/1
bacteria a determined probability
    if not any? yeast with [xcor = min-pxcor] [                ;worm can only eat a yeast if there is
not one already there
    create-1-yeast Yeast-intake-prob  min-pxcor min-pxcor  0 0        ;probability value assigned
by appropriate sliders
    ]
```

```
    create-1-Bacteria Bacteria-intake-prob   min-pxcor min-pxcor g-Bottom-Mucous-Top-Y
g-Top-Mucous-Bottom-Y   ]
end
```

```
to random-position [#xmin #xmax #ymin #ymax]                    ;random-position procedure
  setxy (random-between #xmin #xmax) ( random-between #ymin #ymax)    ;sets x and y cor to
random values bewteen the assigned max and min of x and y
end
```

```
to create-1-yeast  [#prob  #min-x #max-x #min-y #max-y]          ;procedure to create yeast
  if ((random-between 0 100) <= #prob) [                    ;creates yeast if a random value chosen
is less than or equal to the set yeast intake probability
    create-yeast 1 [
       random-position #min-x #max-x #min-y #max-y            ;calls random position procedure
         set color  blue                              ;sets yeast color and size
         set size .9
         set heading 90                            ;need to be heading down lumen so see yeast in
front of them
       set Yeast-adhesion "unstuck"                 ;sets yeast as unstuck and time stuck at 0
       set Yeast-time-stuck 0
   ]
       ]
end
```

```
to create-1-Bacteria [#prob #min-x #max-x #min-y #max-y]          ;procedure to create bacteria
  if ((random-between 0 100) <= #prob)[                    ;creates bacteria if a random value
chosen is less than or equal to the set bacteria intake probability
       create-Bacteria 1 [
      random-position #min-x #max-x #min-y #max-y            ;calls random position procedure
         set heading 90                          ;sets bacteria direction
         set color black                          ;sets bacteria color and size
         set size .9
      set Bacteria-adhesion "unstuck"                        ;sets bacteria as unstuck and time stuck at 0
      set Bacteria-time-stuck 0
```

```
        ]
            ]
end




                              ;Yeast Procedures




to free-yeast                                    ;Free yeast procedure -- already within an
'ask yeast' statement LIZ

  if (Patch-Type = "Lumen" and ( xcor >= (max-pxcor - 0.2) and xcor <= max-pxcor)) [die]
;keeps yeast within the lumen
  let yeast-ahead one-of other yeast in-cone 1 100              ; need to look whether yeast in
front of them -- could be on same patch

  if yeast-ahead = nobody [move-yeast]                      ;if no yeast on patch ahead call
move procedure

  if yeast-ahead != nobody [                              ;Yeast have a chance of slipping by other
yeast in their way
    let x random-between 0 100
    if x < (Yeast-slip-prob - p-Yeast-biofilm ) [move-yeast]
  ]


  let x random-between 0 100          ;yeast stick if a randomly chosen value is less than the
assigned yeast adhesion probability
  if x < (Yeast-adhesion-prob - p-Bacteria-molecule-concentration + p-Yeast-biofilm ) [
    set Yeast-adhesion "stuck"                          ;sets the yeast's state as stuck
    set color yellow
    ]

end
```

```
to stuck-yeast                              ;stuck yeast procedure

  set Yeast-time-stuck (Yeast-time-stuck + 1)          ;increases the yeast time stuck
  let nearby-stuck-yeast other yeast in-radius Yeast-biofilm-radius with [Yeast-time-stuck >=
Yeast-biofilm-time-threshold]  ; check to see if there are any other
                                             ; yeast nearby that have been stuck
a while

  ifelse            ;if yeast have been stuck as long as the set threshold and nearby yeast are stuck
they become biofilm
  (Yeast-time-stuck >= Yeast-biofilm-time-threshold) and any? nearby-stuck-yeast
    [set color red  set Yeast-adhesion "biofilm"]

    [ let x random-between 0 100     ; if no yeast stuck nearby, see if should become unstuck
     if x < Yeast-deadhesion-Prob [
       set Yeast-adhesion "unstuck"                ;sets the yeast's state as unstuck, resets the
yeast's time stuck
       set color blue
       set Yeast-time-stuck 0 ]
    ]


end



to Biofilm-Yeast                              ;yeast biofilm procedure
 set p-Yeast-biofilm (p-Yeast-biofilm + Yeast-biofilm-secretion-rate) ;increases the biofilm value
by the set secretion rate
end



to move-yeast                              ;move yeast procedure
   if (Patch-Type = "Mucous") [                ;if yeast are in the mucous set heading to a
random direction
     if (xcor < -16 and xcor > -15) [
```

```
        if (ycor >= (g-Bottom-Mucous-Bottom-Y ) and ycor <= (g-Top-Mucous-Top-Y ) )
        [ set heading random-between 0 360
           forward g-Brownian-Speed-In-Mucous              ;move forward by determined global
variable value
        setxy xcor + g-HSpeed-In-Mucous  ycor ]] ]          ;set x and y to current x & current y +
defined global vairable
     if (Patch-Type = "Lumen") [                            ;if yeast in the lumen set the heading to 90
degrees and move forward by yeast speed
     if (xcor >= -17 and xcor <= g-End-Pharynx - 2)[
        set heading 45
       setxy xcor random-between 1 -1]
     if (xcor >= g-End-Pharynx - 1.5)[
       set heading -45 + random 90
       setxy xcor 0]
     set heading 45 + random 90
       setxy xcor + Yeast-Speed ycor]


;    if (Patch-Type = "Lumen") [                            ;if yeast in the lumen set the heading to 90
degrees and move forward by yeast speed
 ;      set heading 45 + random 90
 ;      fd Yeast-Speed  ]



     if (Patch-Type = "Cell") [ setxy xcor ycor ]           ;if yeast in epithelial cells set x and y to
current x and y cor
end



to-report random-between [ #min #max ]                     ;report procedure for random-between
  report #min + random-float (#max - #min)                 ;reports a value equal to the min + a
randomly chosen vaule greater than or equal to 0 but less than (max-min)
end
```

;Bacteria Procedures

to Free-bacteria   ;Free bacteria procedure
                                                    ;keeps bacteria within the lumen
   if (Patch-Type = "Lumen" and (xcor >= (max-pxcor - 0.2) and xcor <= max-pxcor)) [die]

  Move-Bacteria   ;calls move-bacteria procedure and the stick
bacteria procedure

                                    ;bacteria stick if a randomly chosen value is less than the assigned
yeast adhesion probability
  let x random-between 0 100
  if x < (Bacteria-adhesion-prob + p-Bacteria-biofilm) [
  set Bacteria-adhesion "stuck"   ;sets bacterium state to stuck
  ]

end

to Stuck-bacteria   ;Stuck bacteria procedure

  set Bacteria-time-stuck (Bacteria-time-stuck + 1)   ;increases the bacteria time stuck

   ifelse   ;if yeast have been stuck as long as the set threshold they
become biofilm & they try to become unstuck if not
    (Bacteria-time-stuck >= Bacteria-biofilm-time-threshold) [set Bacteria-adhesion "biofilm"]

   [let x random-between 0 100   ;Bacteria randomly unstick if a chosen value
is below the Yeast deadhesion probability
    if x < Bacteria-deadhesion-Prob [
     set Bacteria-adhesion "unstuck"   ;sets bacterium state as unstuck and resets
their time stuck counter
     set Bacteria-time-stuck 0
   ]
  ]
end

```
to Biofilm-Bacteria                                      ;Bacterial biofilm procedure
   set p-Bacteria-biofilm (p-Bacteria-biofilm + Bacteria-biofilm-secretion-rate) ;increases their
biofilm value by the set secretion rate
end




to Move-Bacteria                               ;move bacteria procedure
    if (Patch-Type = "Mucous") [                       ;if yeast are in the mucous set heading to a
random direction
      if (xcor < -16 and xcor > -15) [
       if (ycor >= (g-Bottom-Mucous-Bottom-Y ) and ycor <= (g-Top-Mucous-Top-Y ) )
       [ set heading random-between 0 360
          forward g-Brownian-Speed-In-Mucous                ;move forward by determined global
variable value
        setxy xcor + g-HSpeed-In-Mucous  ycor ]] ]        ;set x and y to current x & current y +
defined global vairable
    if (Patch-Type = "Lumen") [                       ;if yeast in the lumen set the heading to 90
degrees and move forward by yeast speed
    if (xcor >= -17 and xcor <= g-End-Pharynx - 2)[
      set heading 45
     setxy xcor random-between 1 -1]
    if (xcor >= g-End-Pharynx - 1.5)[
     set heading -45 + random 90
     setxy xcor 0]
    set heading 45 + random 90
     setxy xcor + Yeast-Speed ycor]

;   if (Patch-Type = "Lumen") [                       ;if yeast in the lumen set the heading to 90
degrees and move forward by yeast speed
;      set heading 45 + random 90
 ;     fd Yeast-Speed  ]


    if (Patch-Type = "Cell") [ setxy xcor ycor ]           ;if yeast in epithelial cells set x and y to
current x and y cor
end
```

```
;   if (Patch-Type = "Mucous") [                          ;if bacteria are in the mucous set heading to a
random direction;;
;
;     set heading random-between 0 360                    ;move forward by determined global variable
value
;        forward g-Brownian-Speed-In-Mucous               ;set x and y to current x & current y +
defined global vairable
;      setxy xcor + g-HSpeed-In-Mucous   ycor ];;;
;
;   if (Patch-Type = "Lumen") [                           ;if bacteria in the lumen set the heading to
ramdom degree value
  ;  if (xcor >= -17 and xcor <= -16)[
  ;     set heading 45
  ;    setxy xcor random-between 1 -1]
  ;  if (xcor >= -15.5)[
  ;    set heading -45 + random 90
  ;    setxy xcor + Bacteria-Speed ycor]
  ;  set heading 45 + random 90
  ;    setxy xcor + Bacteria-Speed ycor]               ;move forward by defined glbal variable
  ;  fd Bacteria-Speed ]                ;set x and y to current x & current y + defined global
vairable


  ;   if (Patch-Type = "Cell") [setxy xcor ycor]          ;if bacteria in epithelial cells set x and y to
current x and y cor

;end



to Bacteria-Secrete              ;Bacteria secretion procedure
  ask bacteria [                 ;bacteria secrete their molecule at X rate which adds to that patch's
concentration
    set p-Bacteria-molecule-concentration (p-Bacteria-molecule-concentration +
Bacteria-molecule-secretion-rate)
   ]
end
```