

# Module 6: Dictyostelium cluster formation & slug movement

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## Aim

- this was planned as a one week project, students should develop a complex model
- teach them about biology: morphogenesis, cellular behavior, ...
- teach them about mathematics: CPM, PDE, coupling

## Description

- good description on what has been done can be found in the report by the students (see section Papers)
- it's been two days of teaching:
  - first explain CPM and let them play with that a little (e.g. cell sorting)
  - explain PDE system we are going to use
    - I had to explain about phase plane analysis quiet a bit
- then on day 3 start to couple PDE & CPM
  - start with coupling in one direction only
    - e.g. first give a fixed gradient and let CPM cells perform chemotaxis
    - then formulate a PDE where a substance is only produced where CPM cells are
  - then couple in both directions (implement the Savill model)
    - perform clustering and slug movement experiment

## Paper

- Savill, N. J., & Hogeweg, P. (1997). Modelling morphogenesis: from single cells to crawling slugs. *J. Theor. Biol*, 184, 229-235. [link](#)
- Stan Marée (2002), From pattern formation to morphogenesis: multicellular coordination in *Dictyostelium discoideum* [link](#)
- Alberto Quintero, Mirko Myllykoski, Anna Igolkina, Alexandra Rohde O'Sullivan Freltoft, Nitya Dixit, Fabian Rost (2012), Morphogenesis and Dynamics of Multicellular Systems, [link](#)

## Morpheus models

h ClusterFormation.xml |h

```
<?xml version='1.0' encoding='UTF-8'?>
```

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<MorpheusModel version="1">
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    <Title>Cluster Formation</Title>
  </Description>
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    <Lattice class="square">
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        <Condition boundary="x" type="constant"/>
        <Condition boundary="y" type="constant"/>
        <Condition boundary="-x" type="constant"/>
        <Condition boundary="-y" type="constant"/>
      </BoundaryConditions>
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  </Space>
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    <TimeSymbol symbol="time"/>
  </Time>
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    <CellType class="medium" name="medium">
      <Property symbol="b" value="0"/>
      <Property symbol="max_c" value="0"/>
      <Property symbol="phase" value="0"/>
    </CellType>
    <CellType class="biological" name="ameba">
      <VolumeConstraint>
        <Strength value="1.0"/>
        <Target value="20"/>
      </VolumeConstraint>
      <Chemotaxis>
        <Layer symbol-ref="c"/>
        <Strength symbol-ref="mu"/>
      </Chemotaxis>
      <Property symbol="b" value="0"/>
      <Property symbol="max_c" value="0"/>
      <PDEReporter>
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        <Maximum symbol-ref="max_c"/>
      </PDEReporter>
      <Property symbol="phase" value="1"/>
      <Property symbol="phaseTime" value="0"/>
      <Equation symbol-ref="phaseTime">
        <Expression>if(phase == 2, phaseTime+MCStime,
0)</Expression>
      </Equation>
    </CellType>
  </CellTypes>
</MorpheusModel>
```

```

    <Equation symbol-ref="phase" name="Rule_2_3">
      <Expression>if(phase == 1 and max_c > 0.1, 2,
if(phase == 2 and phaseTime>phase2duration, 3,
if(phase == 3 and max_c < 0.05, 1,
phase
))) </Expression>
    </Equation>
    <Property symbol="phase2duration" value="2"/>
    <Function symbol="mu">
      <Expression>if(phase == 2, 300, 0)</Expression>
    </Function>
  </CellType>
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    </VolumeConstraint>
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  <Disabled>
    <Chemotaxis>
      <Layer symbol-ref="c"/>
      <Strength symbol-ref="mu"/>
    </Chemotaxis>
  </Disabled> -->
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    <Property symbol="max_c" value="0"/>
    <Property symbol="phase" value="0"/>
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</CellTypes>
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  <Interaction>
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    <Contact type1="ameba" type2="medium" value="2"/>
    <Contact type1="ameba" type2="autoAmeba" value="4"/>
    <Contact type1="autoAmeba" type2="medium" value="3"/>
    <Contact type1="autoAmeba" type2="autoAmeba" value="-15"/>
  </Interaction>
  <MCSDuration symbol="MCStime" value="0.1"/>
  <MetropolisKinetics temperature="1.0" yield="0.1"
stepper="edgelist">
    <Neighborhood>
      <Order>2</Order>
    </Neighborhood>
  </MetropolisKinetics>
</CPM>
<PDE>
  <Layer symbol="c">
    <Diffusion rate="1"/>
    <Initial>
      <InitPDEExpression>
        <Expression>0</Expression>

```

```
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    </Initial>
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        <Condition boundary="-x" value="0"/>
        <Condition boundary="y" value="0"/>
        <Condition boundary="-y" value="0"/>
    </BoundaryConditions>
</Layer>
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    <Diffusion rate="0"/>
    <Initial>
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            <Expression>0</Expression>
        </InitPDEExpression>
    </Initial>
    <BoundaryConditions>
        <Condition boundary="x" value="0"/>
        <Condition boundary="-x" value="0"/>
        <Condition boundary="y" value="0"/>
        <Condition boundary="-y" value="0"/>
    </BoundaryConditions>
</Layer>
<System solver="euler" time-step="0.1">
    <DiffEqn symbol-ref="c">
        <Expression>alpha*(-f -r)</Expression>
    </DiffEqn>
    <DiffEqn symbol-ref="r">
        <Expression>alpha*epsilon*(3.5*c-b-r)</Expression>
    </DiffEqn>
    <Function symbol="epsilon">
        <Expression>if(c < 0.0065, 0.5,
if(c < 0.841, 0.0589,
0.5))</Expression>
    </Function>
    <Function symbol="f">
        <Expression>if(c < 0.0065, 20*c,
if(c < 0.841, -3*c+0.15,
15*(c-1))</Expression>
    </Function>
    <Function symbol="alpha">
        <Expression>if(cell.id != 0, 1, 0)</Expression>
    </Function>
</System>
</PDE>
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            <Dimensions size="10 10 0" center="100 100 0"/>
        </InitRectangle>
    </Population>
</CellPopulations>
```

```

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        <Color value="0" color="white"/>
        <Color value="1.0" color="red"/>
      </ColorMap>
    </PDE>
    <Cells symbol-ref="phase" min="0" max="3"/>
    <Cells symbol-ref="cell.volume" min="15" max="25"/>
    <PDE symbol-ref="c" min="-0.5" max="1.0">
      <ColorMap>
        <Color value="-0.5" color="dark-violet"/>
        <Color value="0" color="white"/>
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      </ColorMap>
    </PDE>
  </Gnuplotter>
</Analysis>
</MorpheusModel>

```

- [Movie: Cluster Formation & cAmp Spirals](#)
- for the movie the system size was 500×500 with 4000 cells randomly placed, everything else was like in the example above

h CrawlingSlug.xml |h

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<?xml version='1.0' encoding='UTF-8'?>
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  </Description>
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```

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</Space>
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</Time>
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        <Property symbol="phase" value="0"/>
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    <CellType class="biological" name="ameba">
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            <Strength value="1.0"/>
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        <Chemotaxis>
            <Layer symbol-ref="c"/>
            <Strength symbol-ref="mu"/>
        </Chemotaxis>
        <Property symbol="b" value="0"/>
        <Property symbol="max_c" value="0"/>
        <PDEReporter>
            <Input symbol-ref="c"/>
            <Maximum symbol-ref="max_c"/>
        </PDEReporter>
        <Property symbol="phase" value="1"/>
        <Property symbol="phaseTime" value="0"/>
        <Equation symbol-ref="phaseTime">
            <Expression>if(phase == 2, phaseTime+MCStime,
0)</Expression>
        </Equation>
        <Equation symbol-ref="phase" name="Rule_2_3">
            <Expression>if(phase == 1 and max_c > 0.1, 2,
if(phase == 2 and phaseTime>phase2duration, 3,
if(phase == 3 and max_c < 0.05, 1,
phase
))) </Expression>
        </Equation>
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            <Expression>if(phase == 2, 50, 0)</Expression>
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```

```

</CellType>
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  <Chemotaxis>
    <Layer symbol-ref="c"/>
    <Strength symbol-ref="mu"/>
  </Chemotaxis>
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  <Property symbol="b" value="0.5"/>
  <Property symbol="max_c" value="0"/>
  <Property symbol="phase" value="0"/>
</CellType>
</CellTypes>
<CPM>
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    <Contact type1="ameba" type2="autoAmeba" value="4"/>
    <Contact type1="autoAmeba" type2="medium" value="3"/>
    <Contact type1="autoAmeba" type2="autoAmeba" value="-2"/>
  </Interaction>
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  </MetropolisKinetics>
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    </Initial>
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      <Condition boundary="-x" value="0"/>
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  </Layer>
  <Layer symbol="r">
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```

```
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  <System solver="euler" time-step="0.1">
    <DiffEqn symbol-ref="c">
      <Expression>alpha*(-f -r)</Expression>
    </DiffEqn>
    <DiffEqn symbol-ref="r">
      <Expression>alpha*epsilon*(3.5*c-b-r)</Expression>
    </DiffEqn>
    <Function symbol="f">
      <Expression>if(c < 0.0065, 20*c,
if(c < 0.841, -3*c+0.15,
15*(c-1)))</Expression>
    </Function>
    <Function symbol="alpha">
      <Expression>if(cell.id != 0, 1, 0)</Expression>
    </Function>
    <Function symbol="epsilon">
      <Expression>if(c < 0.0065, 0.5,
if(c < 0.841, 0.0589,
0.5))</Expression>
    </Function>
  </System>
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  <Equation symbol-ref="r">
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  </Population>
</CellPopulations>
```

```

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            <Dimensions size="5 5 0" center="55 50 0"/>
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    </Population>
</Disabled> -->
</CellPopulations>
<Analysis>
    <Gnuplotter interval="10">
        <Terminal opacity="0.7" name="png"/>
        <PDE symbol-ref="c" min="-0.5" max="1.0">
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                <Color value="-0.5" color="dark-violet"/>
                <Color value="0" color="white"/>
                <Color value="1.0" color="red"/>
            </ColorMap>
        </PDE>
        <Cells symbol-ref="phase" min="1" max="3">
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                <Color value="2" color="green"/>
                <Color value="3" color="red"/>
            </ColorMap>
        </Cells>
    <!--
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    <Cells symbol-ref="cell.volume" min="15" max="25"/>
</Disabled> -->
    <PDE symbol-ref="c" min="-0.5" max="1.0">
        <ColorMap>
            <Color value="-0.5" color="dark-violet"/>
            <Color value="0" color="white"/>
            <Color value="1.0" color="red"/>
        </ColorMap>
    </PDE>
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<Disabled>
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```

```
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  </Gnuplotter>
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      <Y-axis columns="2 3"/>
    </Plot>
  </Logger>
</Disabled> -->
  </Analysis>
</MorpheusModel>
```

- [Movie: Crawling Slug](#)

From: <https://imc.zih.tu-dresden.de/wiki/morpheus/> - **Morpheus**

Permanent link: <https://imc.zih.tu-dresden.de/wiki/morpheus/doku.php?id=documentation:course:module6&rev=1357904876>

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