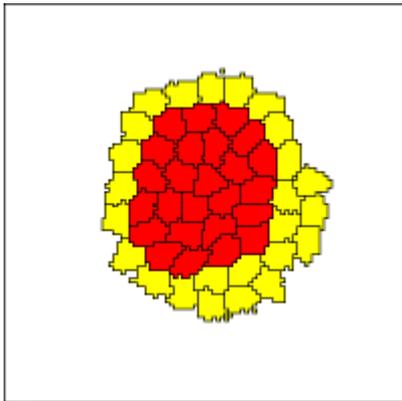# Cellular Potts models

Differential Adhesion: cell sorting in two dimensions

Yellow cells engulf the red cells as a result of differential adhesion

Introduction

This model shows the original cellular Potts model (a.k.a. Glazier-Graner model) of cell sorting based on the Steinberg's differential adhesion hypothesis.

Model description

Two CellTypes are defined, each of which has a VolumeConstraint specifying the cell's target area/volume. In the CPM element, the MetropolisKinetics can be configured and the Interaction energies between cell types are specified.

Although cells can be initialized as single points using e.g. the InitCircle plugin, in this example, the Nodes of each Cell in the CellPopulations are given explicitly. In fact, these Populations are restored results of a previous simulation.

The simulation shows two populations of spatially resolved cells that initially organized in a mosaic fashion. Through differential adhesion, the motile cells sort out and re-organize into an distribution in which one cell type engulfes the other.

Snapshots of the simulation are saved to files named [Title][Time].xml.gz. These files containing intermediate and result states can be opened and used as initial conditions for new simulations. Remember to change StartTime and StopTime accordingly.
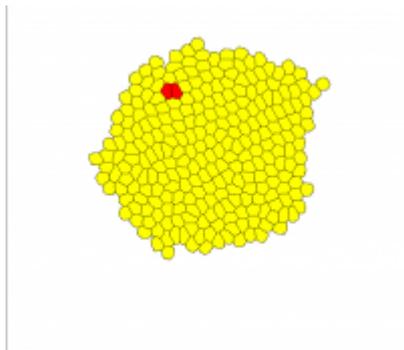
Model

h CellSorting_2D.xml |h

```
extern>http://imc.zih.tu-dresden.de/morpheus/examples/CPM/CellSorting_2D.xml
```

In Morpheus GUI: `File → Examples → CPM → CellSorting_2D.xml`

Reference

Graner F, Glazier J. Simulation of Biological Cell Sorting Using a Two-Dimensional Extended Potts Model. *Phys. Rev. Lett.* 69 (13): 2013–2016, 1992.

Proliferation in two dimensions

Growing cell population

Introduction

This model show a simulation of a growing cell population, using the cellular Potts model.

Model description

This model specifies `CellType` which has a `VolumeConstraint` and a `Proliferation` plugin.

In the `Proliferation` plugin, the `Conditions` for a cell to divide are given. Here, each cell that has more than 90% of the target volume has a small probability to divide. Once a division has taken place, the `Equation` defined in the `Triggers` elements are triggered.

Model

Proliferation_2D.xml

```xml
<?xml version='1.0' encoding='UTF-8'?>
<MorpheusModel version="1">
    <Description>
        <Title>Example-Proliferation2D</Title>
    </Description>
    <Space>
        <Lattice class="hexagonal">
            <Size value="500 500 0"/>
            <BoundaryConditions>
                <Condition boundary="x" type="periodic"/>
                <Condition boundary="y" type="periodic"/>
            </BoundaryConditions>
            <Neighborhood>
                <Order>3</Order>
            </Neighborhood>
        </Lattice>
    </Space>
    <Time>
        <StartTime value="0"/>
        <StopTime value="35000"/>
    </Time>
    <CellTypes>
        <CellType class="biological" name="cells">
            <Property symbol="p" value="5e-5" name="proliferation rate"/>
            <Property symbol="d" value="0" name="divisions"/>
            <Property symbol="c" value="0" name="color"/>
            <VolumeConstraint>
                <Strength value="1.0"/>
                <Target value="250"/>
            </VolumeConstraint>
            <SurfaceConstraint>
                <Strength value="5"/>
                <Target value="0.9"/>
            </SurfaceConstraint>
            <Proliferation>
                <Condition>rand_uni(0,1) &lt; p</Condition>
                <DivisionPlane mode="random"/>
                <Triggers>
                    <Equation symbol-ref="d">
                        <Expression>d+0.5</Expression>
```
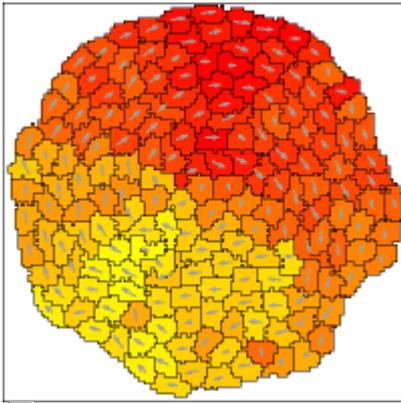
```
                    </Equation>
                    <Equation symbol-ref="c">
                        <Expression>100</Expression>
                    </Equation>
                </Triggers>
            </Proliferation>
            <Equation symbol-ref="c">
                <Expression>if(c>0, c-1, 0)</Expression>
            </Equation>
        </CellType>
    </CellTypes>
    <CPM>
        <Interaction default="0">
            <Contact type1="cells" type2="cells" value="-4"/>
        </Interaction>
        <MCSDuration value="1.0"/>
        <MetropolisKinetics temperature="3" yield="0.1" stepper="edgelist">
            <Neighborhood>
                <Order>2</Order>
            </Neighborhood>
        </MetropolisKinetics>
    </CPM>
    <CellPopulations>
        <Population size="0" type="cells">
            <InitCircle cells="50" type="regular">
                <Dimensions size="35" center="125 250 0"/>
            </InitCircle>
        </Population>
    </CellPopulations>
    <Analysis>
        <Gnuplotter clean="true" interval="50" timename="false">
            <Terminal name="png"/>
            <Cells symbol-ref="c" min="0" max="1.0">
                <ColorMap>
                    <Color value="1.0" color="red"/>
                    <Color value="0" color="yellow"/>
                </ColorMap>
            </Cells>
        </Gnuplotter>
    </Analysis>
</MorpheusModel>
```

In Morpheus GUI: File → Examples → CPM → Proliferation_2D.xml

Persistence

Persistence of individual cells causes self-organized collective motion

Introduction

This example shows self-organized collective motion of cells as a result of persistence ('cellular inertia'). A similar model has recently been used in ([Czirok et al., 2013](#)).

Description

The model uses the `Persistence` plugin that causes cells to prefer to move in their current direction. The direction is stored in a `PropertyVector` that is used to plot the color and arrows in `Gnuplotter`.

The model is simulated in a circular domain with constant boundary conditinos, which can be set up in `Lattice / Domain / Circle`. The value for the constant boundary is specified in CPM / `BoundaryValue`.

Try it!

- Change the boundary conditions from circular=constant to x/y=periodic and observe the resulting collective motion.
- Change the `decay-time` of `Persistence` (specifying the 'memory').
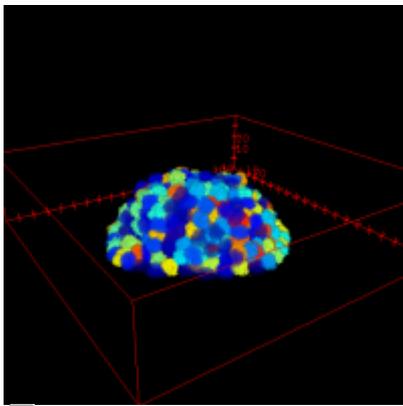
Model

h Persistence_2D.xml |h

```
extern>http://imc.zih.tu-dresden.de/morpheus/examples/CPM/Persistence_2D.xml
```

Reference

Czirók A, Varga K, Mehes E, Szabo A, Collective cell streams in epithelial monolayers depend on cell adhesion. *New J. Phys.* 15 075006, 2013.

Proliferation in three dimensions

Cell population grown from single initial cell

Introduction

This model show a CPM simulation of a growing cell population in 3D.

Model description

This model specifies `CellType` which has a `VolumeConstraint` and a `Proliferation` plugin. In the `Proliferation` plugin, the `Conditions` for a cell to divide are given. Here, each cell that has more than 90% of the target volume has a small probability to divide. Once a division has taken place, the `Equation` defined in the `Triggers` elements are triggered.

In this model, two `medium` cell types have been defined. One of these (called matrix) is used to represent a matrix with higher adhesivity. This is done by (1) defining the 'matrix' cell type as a `BoundaryCondition` of the -z boundary in the CPM and (2) providing lower contact energy for cell-matrix interaction than for cell-medium interactions.

The simulation is visualized using the `TiffPlotter` that saves TIFF image stacks that can be loaded by image analysis software such as Fiji and displayed using Fiji's 3D Viewer plugin.

Model

h Proliferation_3D.xml |h

```
extern>http://imc.zih.tu-dresden.de/morpheus/examples/CPM/Proliferation_3D.x
ml
```

In Morpheus GUI: `File → Examples → CPM → Proliferation_3D.xml`