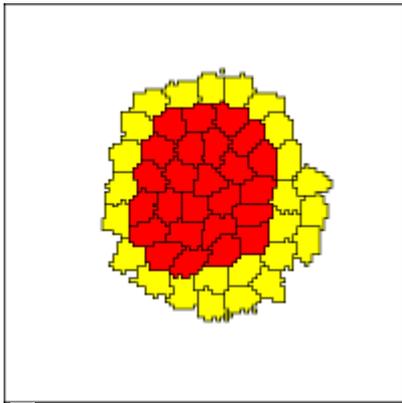# Cellular Potts models

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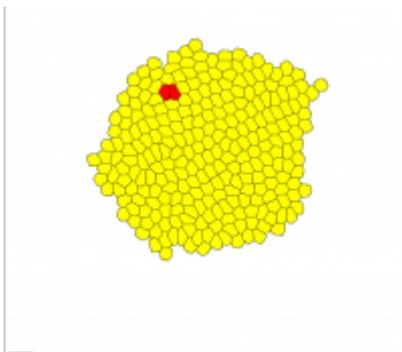
In Morpheus GUI: Examples → CPM → CellSorting_2D.xml

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.
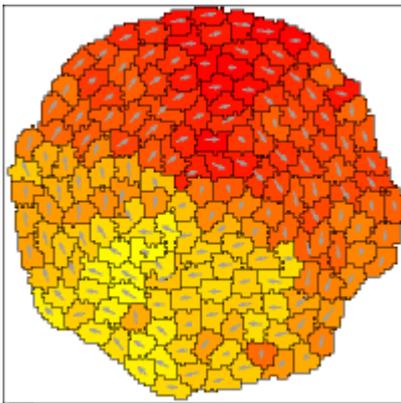
Model

h Proliferation_2D.xml |h

```
extern>http://imc.zih.tu-dresden.de/morpheus/examples/CPM/Proliferation_2D.xml
```

In Morpheus GUI: 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
```
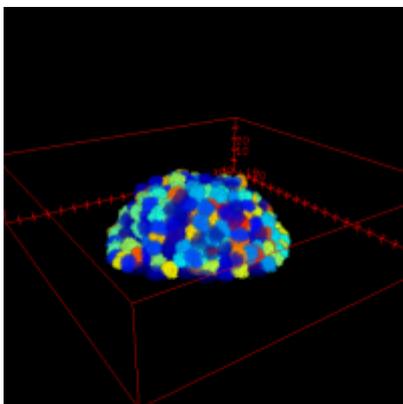
In Morpheus GUI: Examples → CPM → `Persistence_2D.xml`

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: Examples → CPM → Proliferation_3D.xml

Run and Tumble

Modeling cell movements as a Levy walk

Introduction

This example models a single cell that moves according to a Levy walk: a random walk with occassional occurrence of long straight walks.

Model description

The model defines a CPM cell that has two properties:

- A `PropertyVector` that gives the direction of movement and
- A `Property` that defines the time when this direction of movement is changed.

The change in direction is using a `VectorRule`. In this case, it specifies a new random direction for each of the 3 x,y,z coordinates separately: `move_dir = sin(angle), cos(angle), 0` where `angle = rand_uni(0, 2*pi)`.

This is calculated with an `Event`. Upon triggering, this sets the new direction and a waiting time until the next change of direction. To model a superdiffusive Levy walk, this waiting time is chosen from an exponential distribution: `change_time = time + 20 * rand_gamma(0.5, 5)`

Finally, the cell is made to move in the chosen direction using `DirectedMotion` that takes the `PropertyVector` as input.
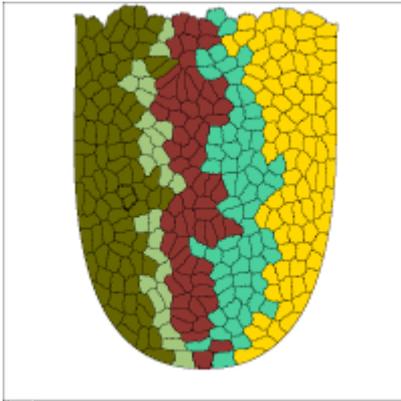
Model

h RunAndTumble.xml |h

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

In Morpheus GUI: Examples → CPM → RunAndTumble.xml

Stem cells in the intestinal crypt

Asymmetric cell division and changing cell type

Introduction

This illustrative example shows the emergence of clonal populations from stem cells in an intestinal crypt. Stem cells in the bottom of the crypt divide asymmetrically and produce a population of transit amplifying (TA) cells. For each of the TA cells, the color indicates the stem cell is it derived from.

Model description

This model shows several new modeling features, available as of Morpheus 1.2.

Loading domain from image

The crypt-like domain is specified by loading an external 8-bit TIFF image file using `Lattice/Domain/Image`.

Asymmetric cell division

Stem cells divide asymmetrically using the new `ChildID` handles in the `Proliferation` plugin. This sets a user-defined symbol (here called `daughter`) to either 1 or 2. This symbol can then be used to distinguish both daughter cells and treat them differently. In this example, it used to set the stemness (`s`) of one daughter to 1 and the stemness of the other daughter cell to 0.

Conditionally changing cell types

When a cell looses its stemness `s`, it is moved to the TA cell type. This is done using the new `ChangeCellType` plugin.

Upon satisfyiug its `Condition`, `ChangeCellType` moves the cell to the specified new cell type. By default, all the properties of a cell that exist in both cell type context are maintained and unspecified ones are set to their default values. This default behavior can be overridden using `Triggers` that specify `Rules` stating how to deal with specific properties.

PopulationReporter

The new `PopulationReporter` allows the collection of statistical data about the cell population. Here, it is used to count the sizes of the various clonal populations. This number of reported into a `Global` and subsequently written to file and plotted using a `Logger`.

Model

h Crypt.xml |h

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

In Morpheus GUI: Examples → CPM → Crypt.xml

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