Using graph approach for managing connectivity in integrative landscape modelling

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Overview and context

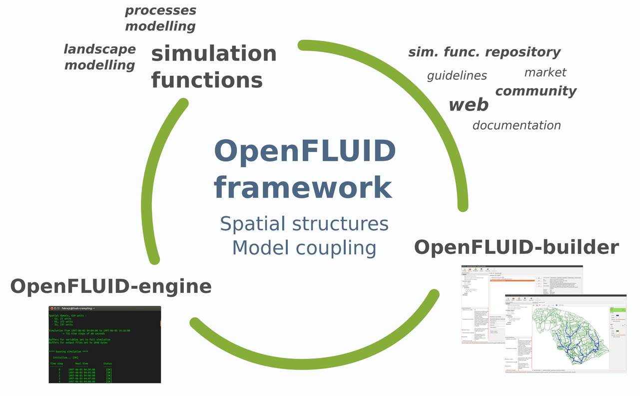
Modelling cultivated landscapes requires an interdisciplinary approach (hydrology, atmospheric sciences, agronomy...). Furthermore, an accurate representation of the landscape elements and their connectivity is of great importance.

OpenFLUID [1] framework uses graph theory concepts i) to help modelers and bring them effective solutions for either simple landscape simulation and for multi-simulations in complex and dynamically evolving landscapes, and ii) for users using already developed representation landscape models to developers who need to develop own landscape discretization procedures.

In cultivated landscapes, spatial arrangements, discontinuities and connectivity are known to have great impacts on water flows, mass and energy fluxes. An **accurate representation** of these specific features is needed which can not be provided by classical representation by matrix (e.g. GIS raster approachs).

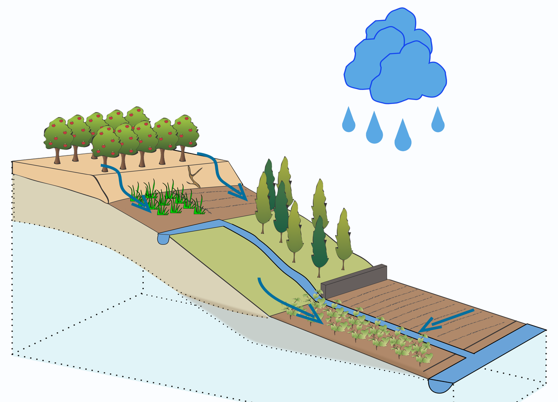
To avoid incorrect representation, a **graph approach** is used where:
- each element of the landscape is represented by a **node**,
- and relations between elements by **edge.**

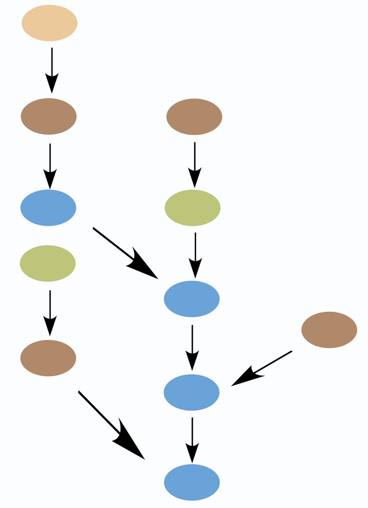
Nodes can embed informations such as geometry and morphology (area, slope...), or distributed properties (infiltration rates, soil occupation...) depending of the simulation context.



OpenFLUID Software

The OpenFLUID platform is a software environment for modelling and simulation of spatial functionning of farmed landscapes. The platform is made of a software framework, software applications and tools, a development environment for models, and shared resources for modellers, developers and users.
The software applications and tools, such as graphical or command line user interfaces, allows the users to interact with the simulations (preparation, monitoring and results processing).



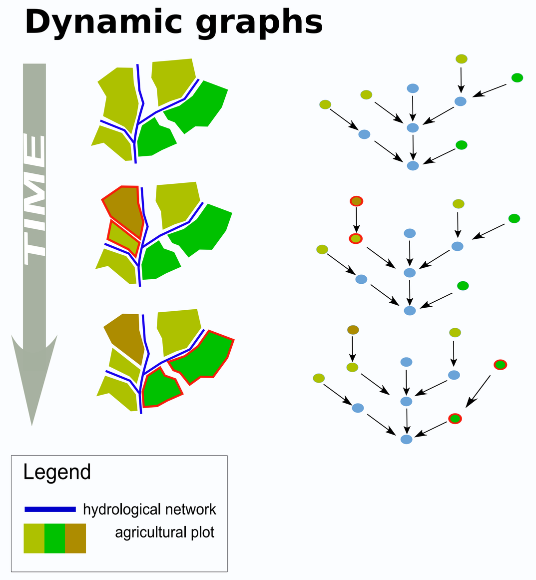


This example shows a landscape and the water flows produced during a rain event. The graph approach represents surface elements (agricultural plots) by green and brown nodes, linear elements (channels) by blue nodes and the edges represent the water fluxes between each element.
Once the graph is created, it is loaded into the OpenFLUID framework and used as support for the simulation.

Graph management in OpenFLUID

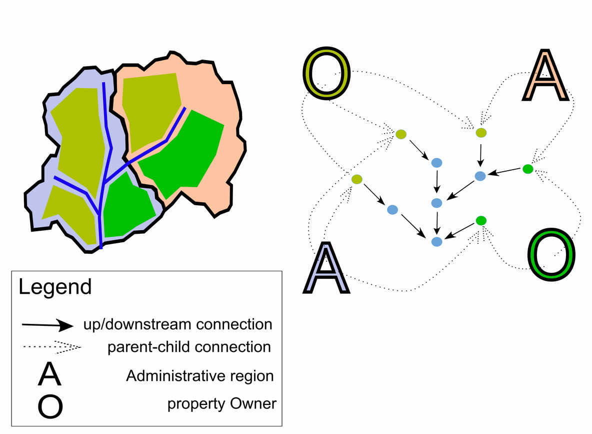
Landscape representation using a graph approach is fully operational in OpenFLUID; graph tools are available such as graph consult, graph traversal algorithms or graph modifications. Graphs are stored into XML based files which are editable and readable by common XML editors or by the OpenFLUID graphical interface.
The **OpenFLUID-landr** library (relied upon common open-source spatial libraries) allows to use and develop specific extensions (e.g. Geo-MHYDAS extension [2]) for managing large landscapes or to define specific connectivity rules.

Dynamic graphs



Graph evolution during simulation is allowed such as elements creation or deletion, or connection modifications.

Hierarchical graphs



OpenFLUID manages hierarchical graphs and offers two types of connection:
- up-downstream connections (e.g. for flux transfers...)
- parent-child connections (e.g. for grouping entities by administrative region...)

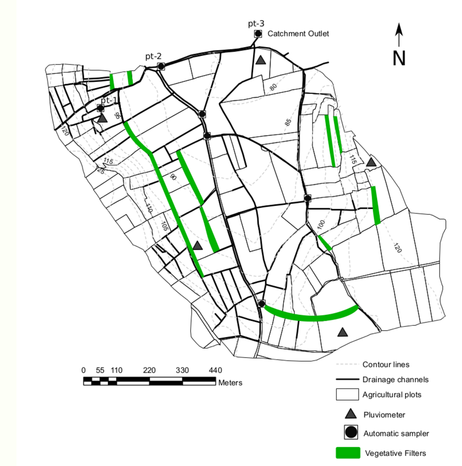
The graph, support for the distributed fluxes

The simulation of the transfer processes is made throught the different landscape units and lean on the graph connections. Simulation processes are expressed by variable calculations at different time steps on each unit (spatio-temporal modelisation).

The OpenFLUID framework is commonly used on the modelling of the following processes:
- surface hydrology (infiltration, runoff)
- surface flows (network transfer)
- surface-groundwater exchanges
- soil-plant-atmosphere transfers (evaporation, transpiration)
- fate and transport of organic pollutant (pesticides)
- erosion

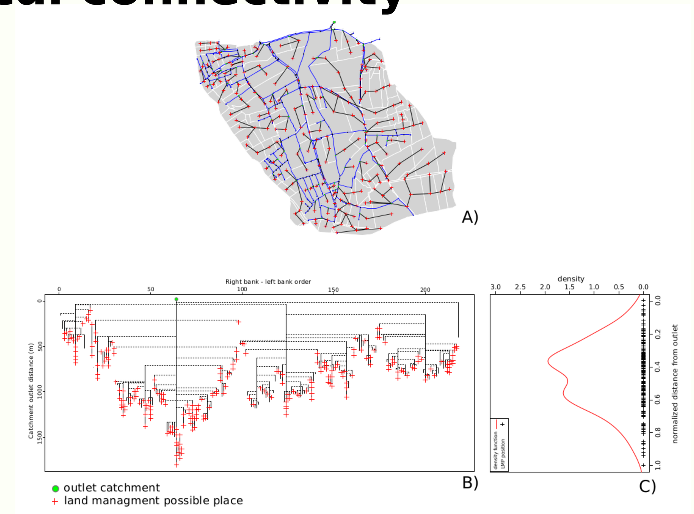
Application examples

MHYDAS-Erosion : an erosion model dealing with sedimentological connectivity



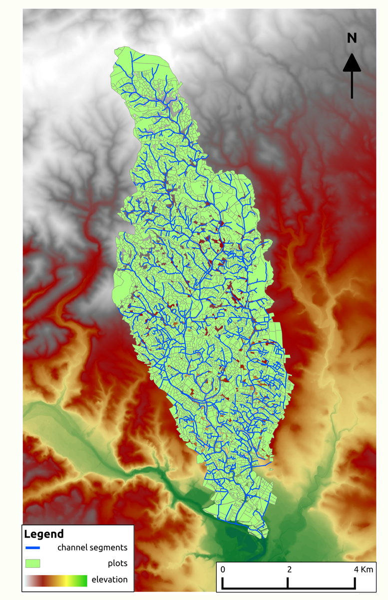
Meteo-Hydro-sedimentological equipments of Roujan agricultural catchment (France)

MHYDAS-Erosion [3] is able to simulate sediment transport, erosion and deposition by rill and interrill processes. Its originality stems from its capacity to integrate the impact of land management practices (LMP) - like vegetative filters - as key elements controlling the sedimentological connectivity in agricultural catchments. The LMP dynamic behaviours are then integrated into the model as a time-dependent function of hydrological variables and LMP characteristics. Different LMP spatial distributions can be simulated and can offer a first step for optimization LMP application into agricultural catchments [4].

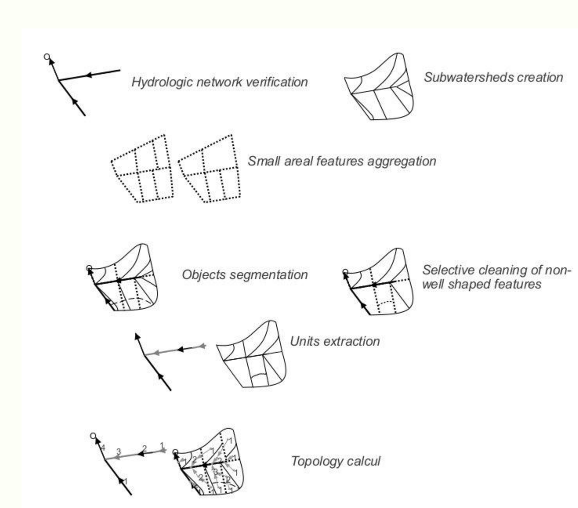


Schematic view of localisation of land management practices over Roujan catchment, A) Catchment topology representation, B) Catchment represented as a directed tree with the potential sites of LMPs and C) Probability density function of LMPs potential sites

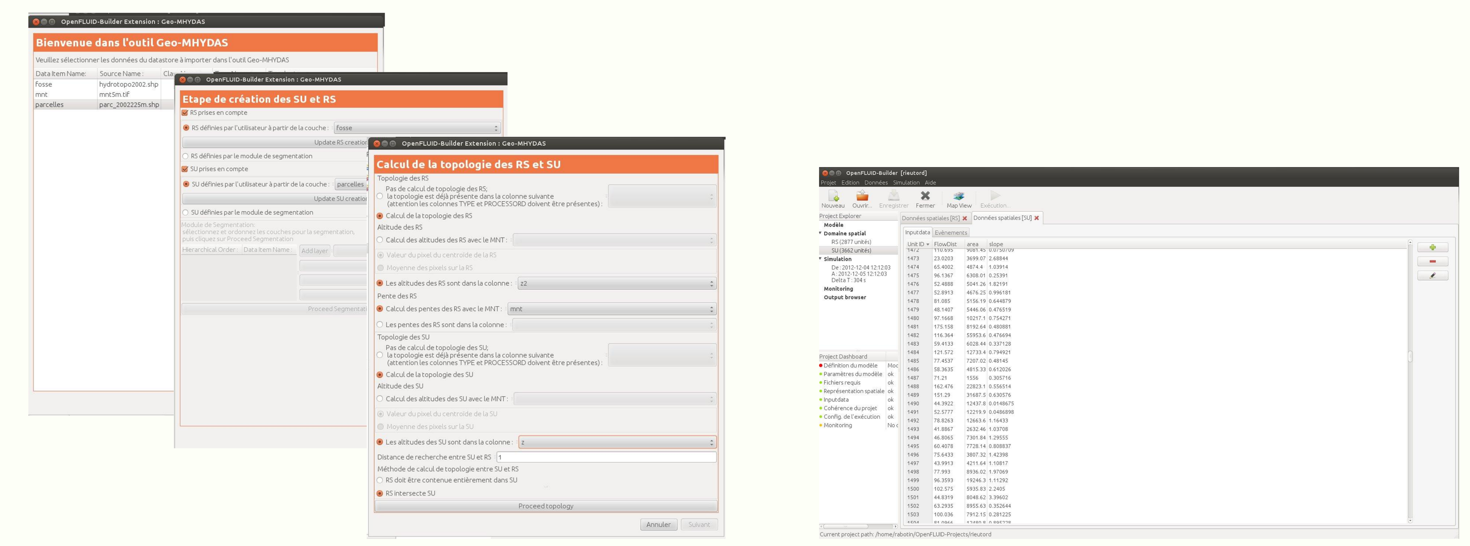
Using Geo-MHYDAS extension on a large landscape



This landscape is made by 2877 channel segments and 3662 plots.
Landscape discretization, connectivity calculations and graph creation has been made by the Geo-MHYDAS [2] extension (developped with the OpenFLUID-landr library).

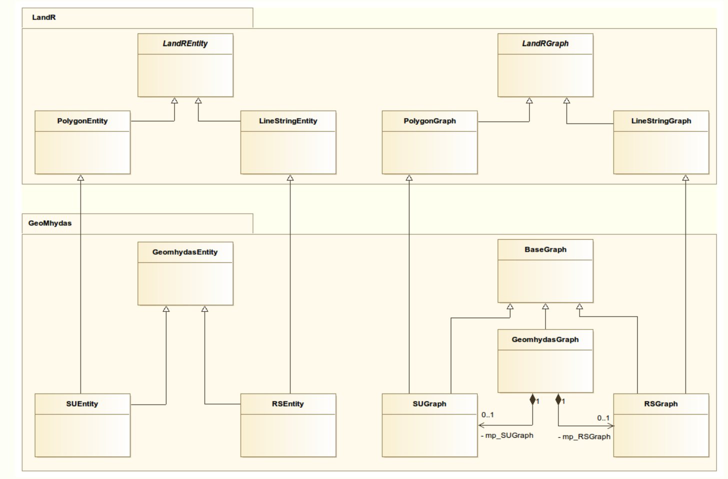


Geo-MHYDAS processes



Geo-MHYDAS allows user to manage geomatic algorithms with no GIS expert skills needed by just following the several steps reachable by the graphical interface. Less than several minutes on a common computer is needed to manage the landscape, create the graph and the whole parameters.

Developing own landscape discretisation and graph creation with OpenFLUID-landr library



OpenFLUID-landr library class diagram

```
bool TopoGraphFunc::initializeRun(
   const openfluid::base::SimulationInfo* /*SimInfo*/)
{
  mp_Graph = new geomhydas::core::GeomhydasGraph();

  mp_Graph->addALayer(*mp_InRSVector, "RSLayer");
  mp_Graph->addALayer(*mp_InSUVector, "SULayer");
  mp_Graph->addALayer(*mp_Raster, "mnt");

  mp_Graph->buildGraph();

  mp_Graph->setAltitudesFromRaster("mnt");

  mp_Graph->setRSTopologyComputation(new geomhydas::tools::LineOrientation());

  geomhydas::tools::TopologyComputation* Comput =
     new geomhydas::tools::MaxSlope();
  Comput->setSUEdgeRSLineRelationship(openfluid::landr::LandRTools::CONTAINS,
                                   0.0001);
  Comput->setWithTopoSUChoice();
  mp_Graph->setSUTopologyComputation(Comput);

  mp_Graph->computeTopology();
  mp_Graph->computeProcessOrder();

  mp_Graph->getSUGraph()->createVectorRepresentation(
     openfluid::base::RuntimeEnvironment::getInstance()->getOutputDir(),
     "SUGraph.shp");

//  printNeighbours();
  printEntities();

  createOutSUVector("SU2.shp");
  createOutRSVector("RS2.shp");

  return true;
}
```

Example of a developed code based on the OpenFLUID-landr library

OpenFLUID-landr is an object-oriented C++ library based on common open source spatial libraries (GEOS, OGR, GDAL). Developers can create own landscape discretization and graph creation rules with it.
Using OpenFLUID framework allows to focus only on the scientific part of the developed code, the other fonctionnalities are automatically managed by the OpenFLUID framework (exceptions management, data validity, result formats...)

Althought the OpenFLUID software is commonly used on hydrology processes, the OpenFLUID-landr library is generic enough to be used for other thematics (landscape ecology, fire model survey...)

Future developments

The next evolutions of the OpenFLUID framework :
- the ability to embed informations on graph edges,
- enhancement of the OpenFLUID-landr library for managing temporal modifications of the landscape discretisation,
- release of the next version of Geo-MHYDAS available to download.

References

[1] Fabre, J.C., Louchart, X., Moussa, R., Dagès, C., Colin, F., Rabotin, M., Raclot, D., Lagacherie, P. and Voltz, M. 2010. OpenFLUID: a software environment for modelling fluxes in landscapes, LANDMOD2010, Montpellier, France
[2] Lagacherie, P., Rabotin, M., Colin, F., Moussa, R. and Voltz, M., 2010. Geo-MHYDAS: A landscape discretization tool for distributed hydrological modeling of cultivated areas, Computers \& Geosciences, 36, p.1021 - 1032.
[3] Gumiere, S.J., Raclot, D., Cheviron, B., Davy, G., Louchart, X., Fabre, J.C., Moussa, R. and Le Bissonnais, Y. 2011. MHYDAS-Erosion: a distributed single-storm water erosion modelfor agricultural catchments, Hydrological Processes, 25, p.1717--1728.
[4] Gumiere, S.J., Bailly, J.S., Cheviron, B., Raclot, D. and Le Bissonnais, Y. Sensibility analyses of a Water Erosion Model to the Spatial Distribution of Land Management Practices. (*In preparation.*)

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