The integration of land change modeling framework FUTURES into GRASS GIS 7

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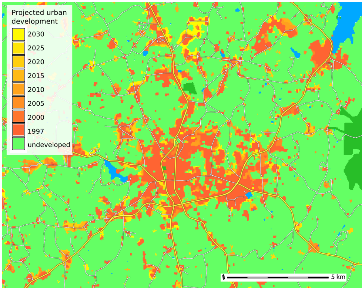
FUTURES

FUTure Urban-Regional Environment Simulation (FUTURES)

- stochastic, patch-based land change model
- simulates urban growth
- model accounts for location, quantity, and pattern of change
- incorporates positive feedbacks (new development attracts more development)
- allows spatial non-stationarity



[Meentemeyer et al., 2013]

FUTURES: Multilevel Simulations of Emerging Urban–Rural Landscape Structure Using a Stochastic Patch-Growing Algorithm

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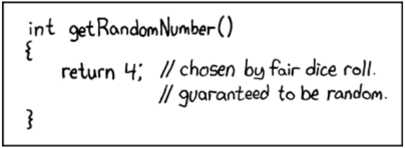
We present a multilevel modeling framework for simulating the emergence of landscape spatial structure in urbanizing regions using a combination of field-based and object-based representations of land change. The FUTure Urban-Regional Environment Simulation (FUTURES) produces regional projections of landscape patterns using coupled submodels that integrate nonstationary drivers of land change: per capita demand, site suitability, and the spatial structure of conversion events. Patches of land change events are simulated as discrete spatial objects using a stochastic region-growing algorithm that aggregates cell-level transitions based on empirical estimation of parameters that control the size, shape, and dispersion of patch growth. At each time step, newly constructed patches reciprocally influence further growth, which agglomerates over time to produce patterns of urban form and landscape fragmentation. Multilevel structure in each submodel allows drivers of land change to vary in space (e.g., by jurisdiction), rather than assuming spatial stationarity across a heterogeneous region. We applied FUTURES to simulate land development dynamics in the rapidly expanding metropolitan region of Charlotte, North Carolina, between 1996 and 2030, and evaluated spatial variation in model outcomes along an urban–rural continuum, including assessments of cell- and patch-based correctness and error. Simulation experiments reveal that changes in per capita land consumption and parameters controlling the distribution of development affect the emergent spatial structure of forests and farmlands with unique and sometimes counterintuitive outcomes. *Key Words: fragmentation, land change model, nonstationarity, object-based, region growing algorithm.*

The dark side of FUTURES

- no documentation
- know-how limited to certain colleagues
- code not reusable
- different versions of code
- no central storage for code
- extensive manual data preparation
- bad choice of programming language



https://xkcd.com/221

Open source approach

We hope FUTURES can make broader impact in land change community...

...but more than just releasing the code online is needed.

We can take example from many open source projects which have established ways and technologies for

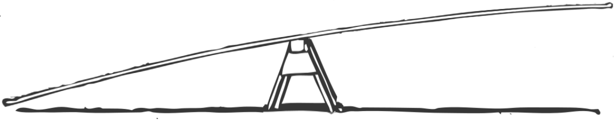
- collaboration
- code development and distribution
- providing documentation, user support

Integration

Standalone vs. integrated into open source GIS:

+ all standard GIS tools and algorithms available
+ distribution and installation across all platform solved
+ established ways to provide documentation
+ existing user base with support

– less flexibility in certain aspects
– need to learn to use the particular GIS

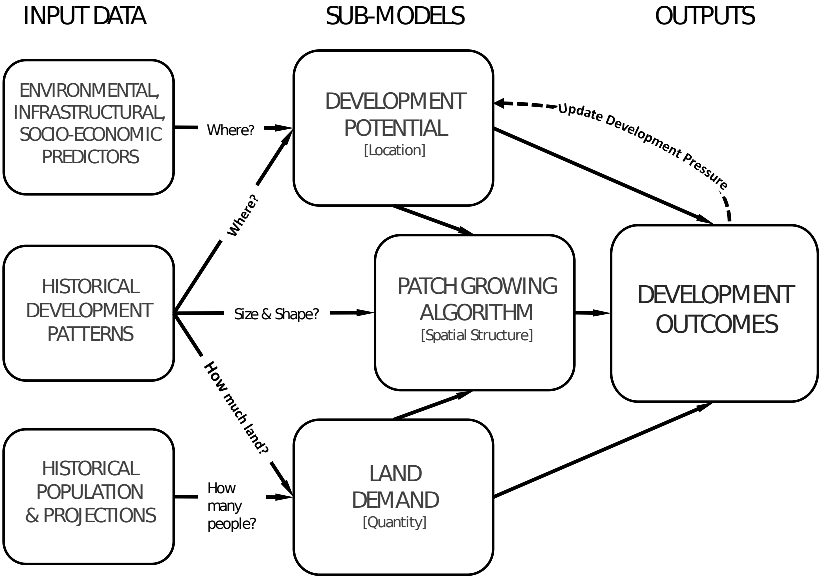


GRASS GIS

Why integrate FUTURES into GRASS GIS 7?

- able to process large datasets
- runs on HPC clusters
- efficient I/O libraries
- modular architecture – modules in C/C++ and Python, R
- automatically generated CLI and GUI
- addons hosted on OSGeo servers
  - easy installation: `> g.extension r.futures`
  - daily compiled binaries for Windows (thanks to M. Landa, FCE CTU in Prague)
  - maintained by community and developers (API changes)

FUTURES conceptual diagram



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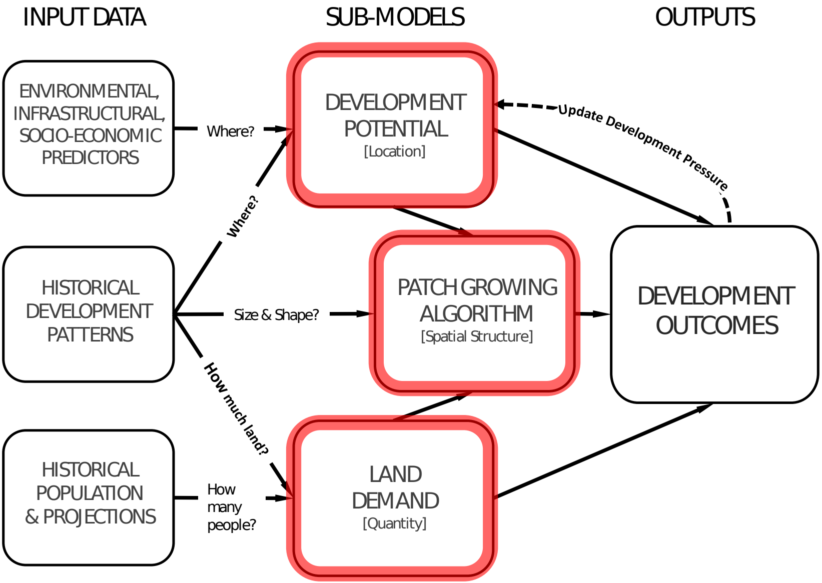

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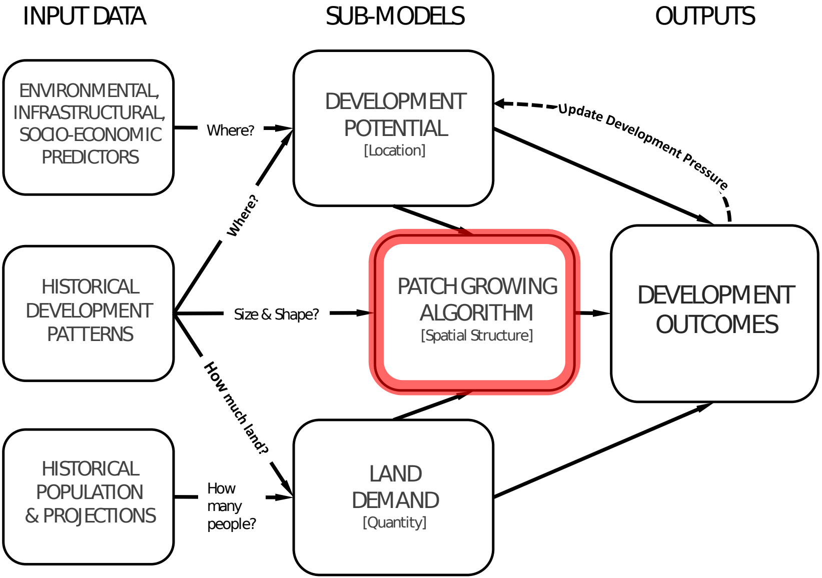
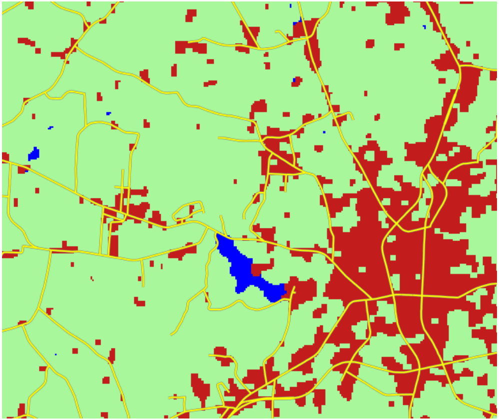


Patch Growing Algorithm

- stochastic algorithm
- converts land in discrete patches



- implemented in C/C++
- computationally demanding
- inputs are patch characteristics (distribution of patch sizes and compactness) derived from historical data

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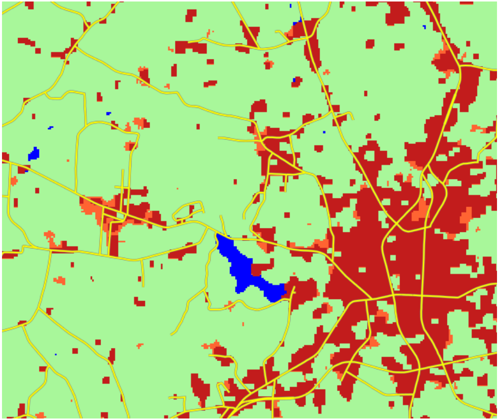

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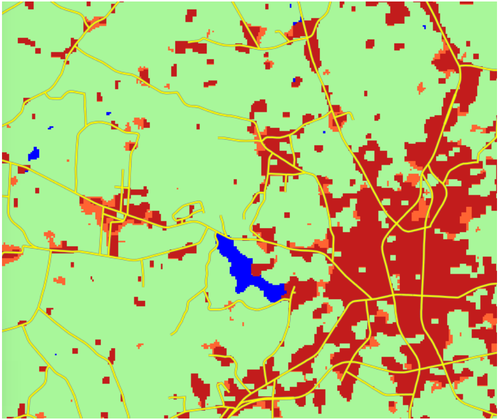

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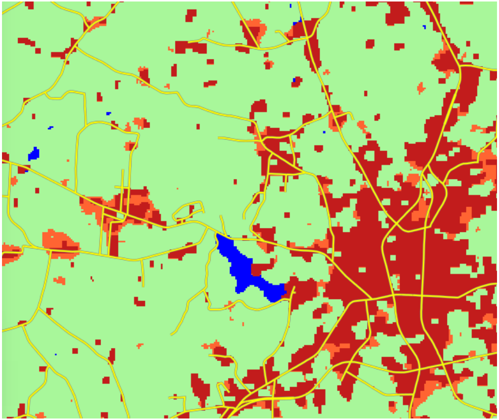

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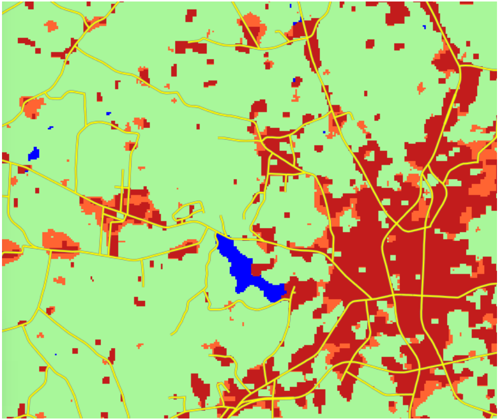

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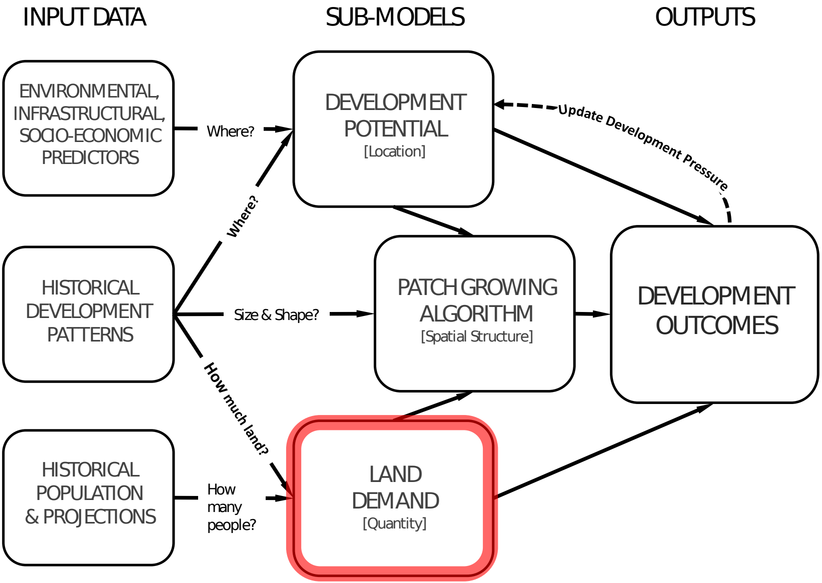
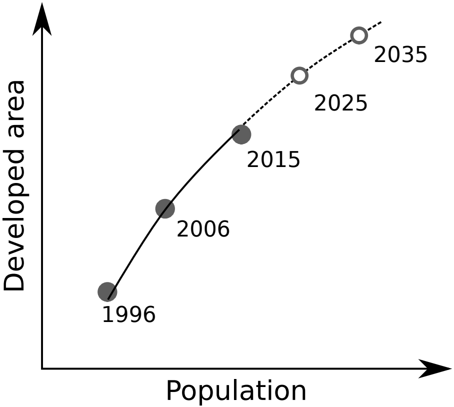


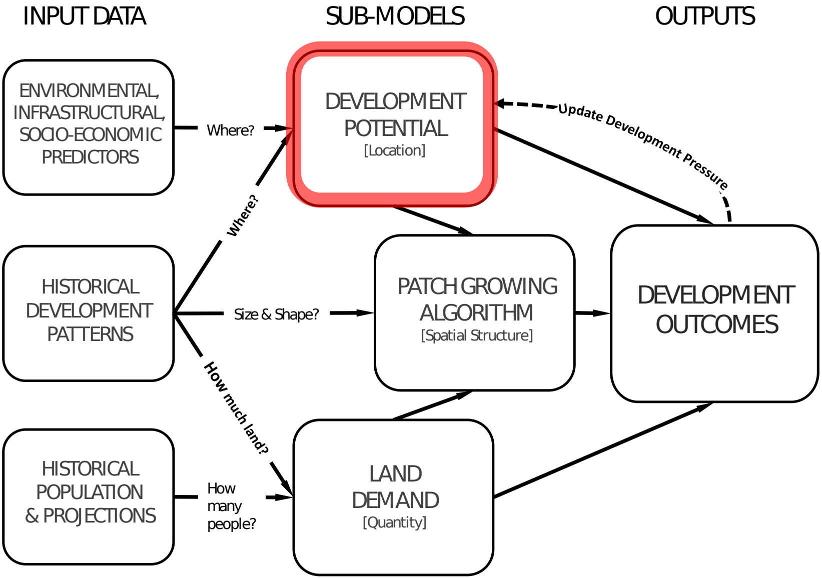
DEMAND submodel

- estimates the rate of per capita land consumption specific to each subregion
- extrapolates between historical changes in population and land conversion



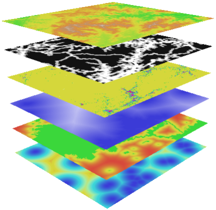
- inputs are historical landuse, population data, population projection
- ordinary least squares regression (linear or logarithmic relationships)
- informally implemented as R scripts and ArcGIS workflows

FUTURES conceptual diagram



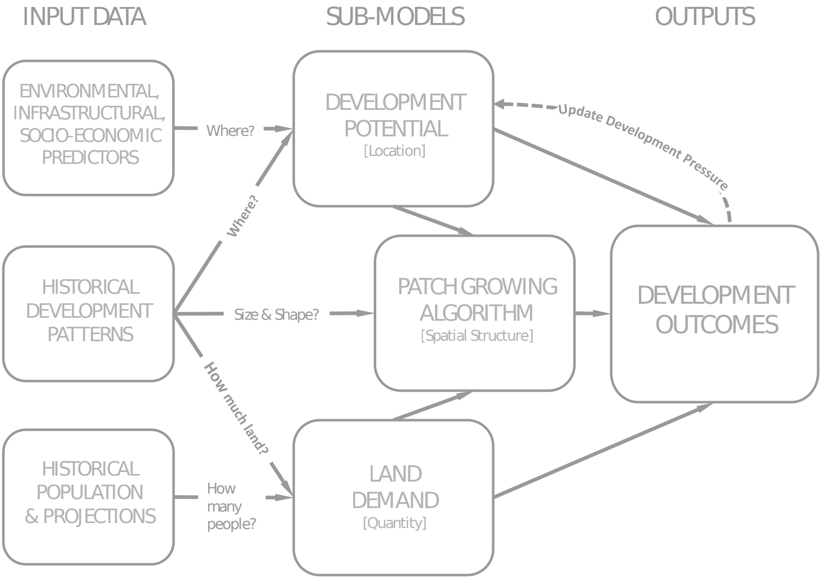
POTENTIAL submodel

- multilevel logistic regression for development suitability
- accounts for variation among subregions (for example policies in different counties)



- inputs are uncorrelated predictors (distance to roads and development, slope, ...)
- original implementation
  - data preparation in ArcGIS
  - regression coefficients derived in R
  - potential and probability surface recomputed after each step in the main C code

Implementation overview



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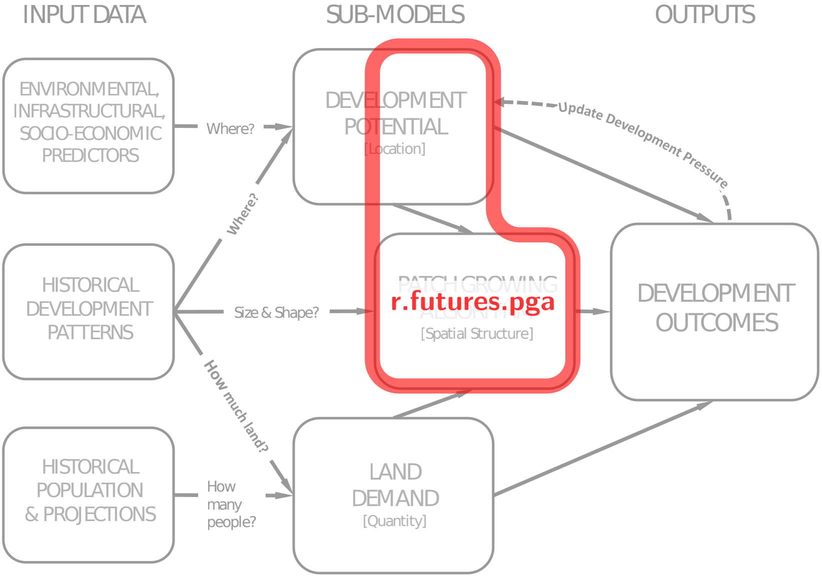

r.futures.pga

Originally standalone C++ code converted into GRASS GIS addon

- efficient raster reading and writing
- fixed segfaults
- general cleanup (dead code), revised input options

```
r.futures.pga [-s] developed=name predictors=name[,name,...]
demand=name devpot_params=name discount_factor=value
...
incentive_table=name [constrain_weight=name] [random_seed=value]
output=name [output_series=basename] [--overwrite] [--help]
[--verbose] [--quiet] [--ui]
```

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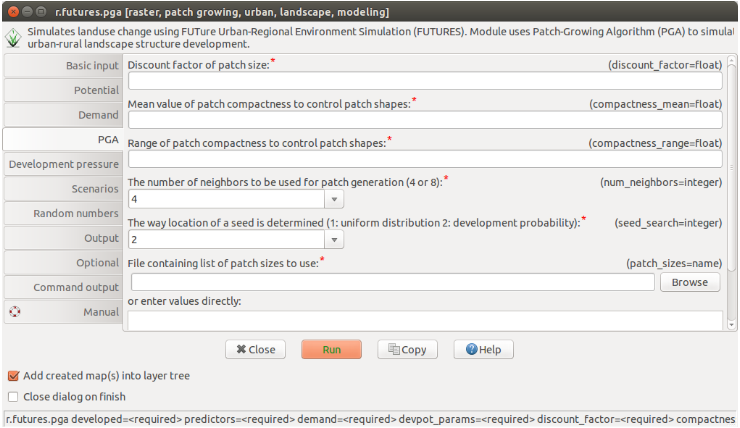

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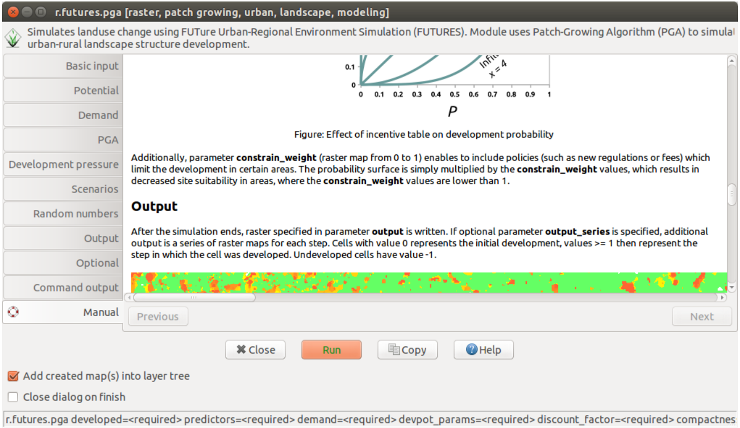

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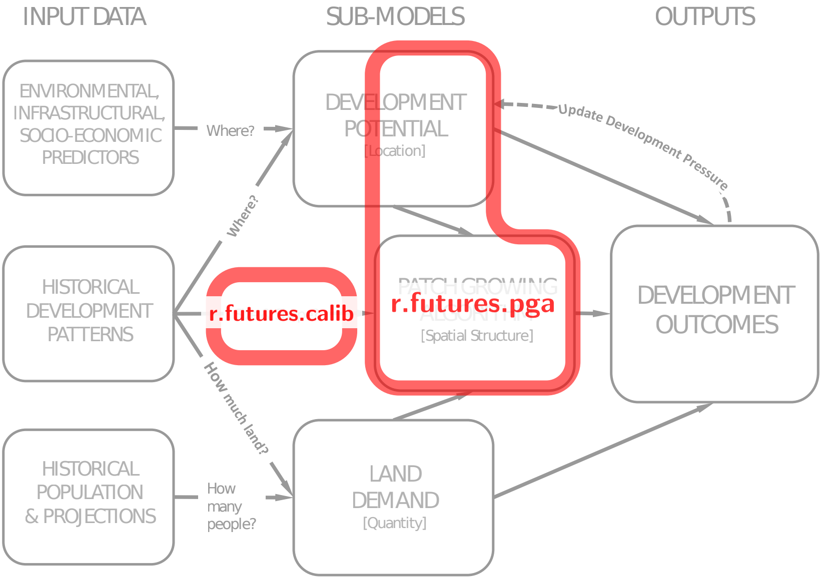
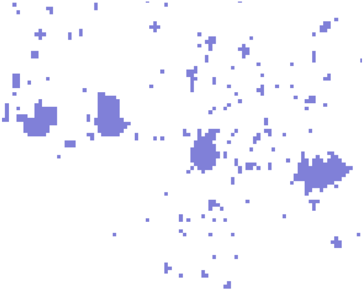


r.futures.calib

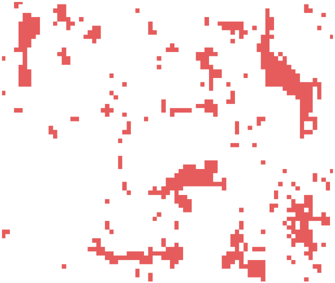
New addon written in Python for automated calibration of patch characteristics

- provides optimal patch parameters for r.futures.pga by comparing observed land change pattern with the simulated pattern
- runs in multiple processes

Higher compactness



Lower compactness



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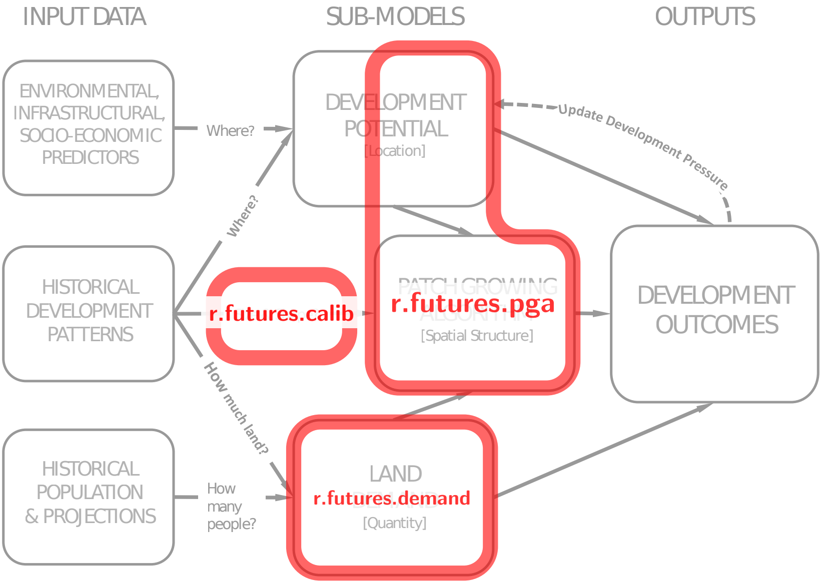

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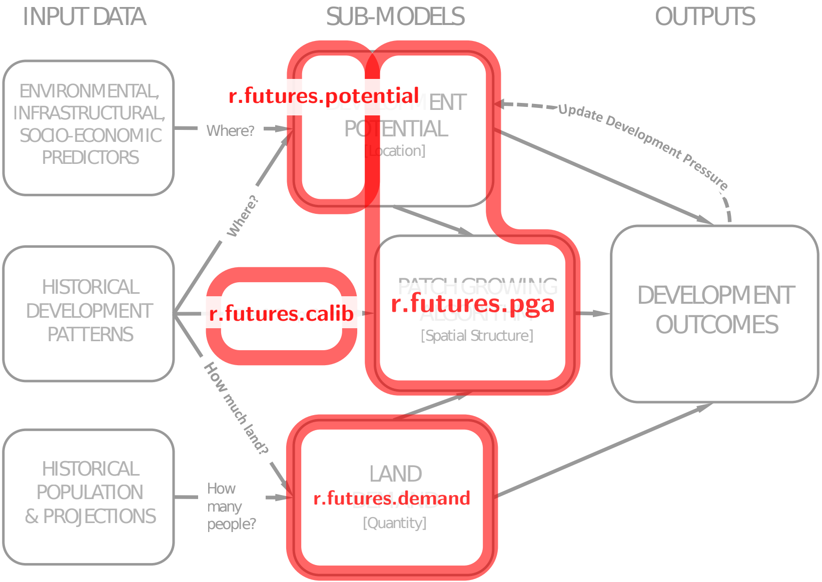


r.futures.potential & r.futures.demand

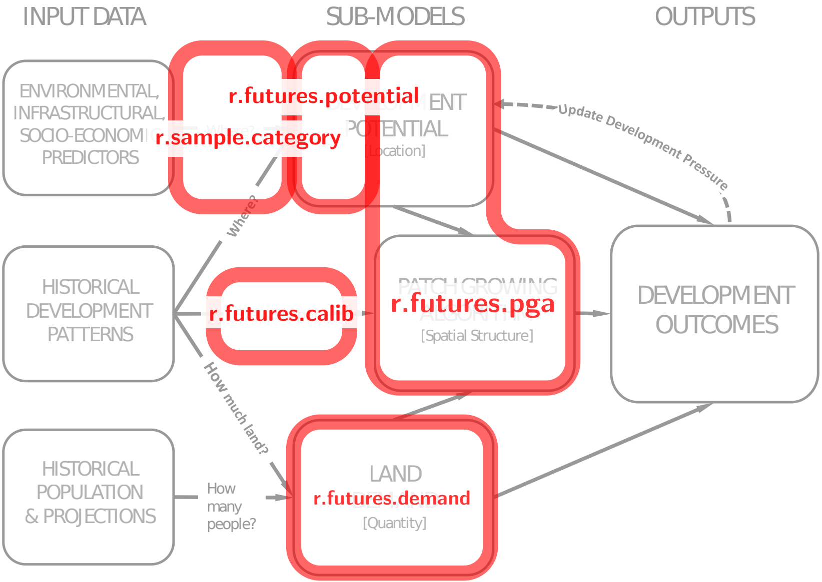
Implementation still needed for

- r.futures.demand – Python and Numpy
- r.futures.potential
  - R wrapped in Python to provide standard GRASS interface
  - using `dredge` from R package MuMIn[1] for automated model selection (read the dredge disclaimer before using)

DEMAND and POTENTIAL statistical models can be implemented in different ways, but we need reference implementation.

[1] http://cran.r-project.org/web/packages/MuMIn/MuMIn.pdf

Implementation overview



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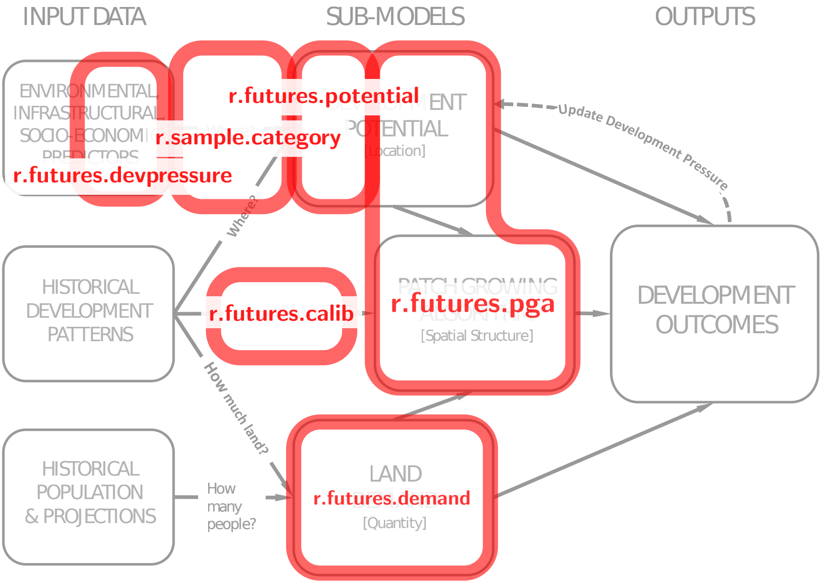
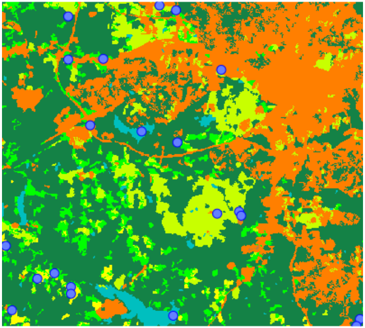


Data preprocessing for POTENTIAL

Two new Python modules needed for FUTURES data preprocessing, but can be used for other applications:

r.sample.category

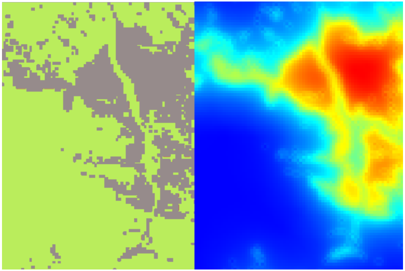
Create sampling points from each category in a raster map



source: r.sample.category manual page

r.futures.devpressure

Moving window computation of distance decay effect



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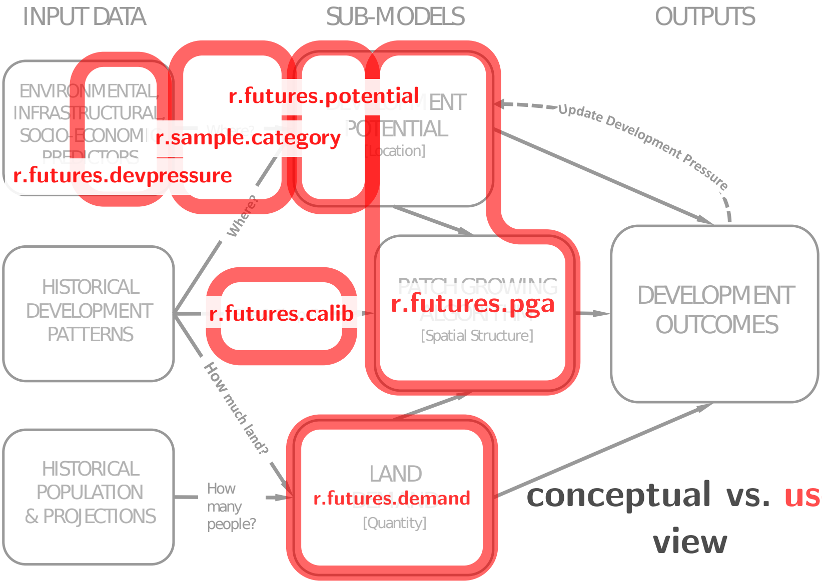


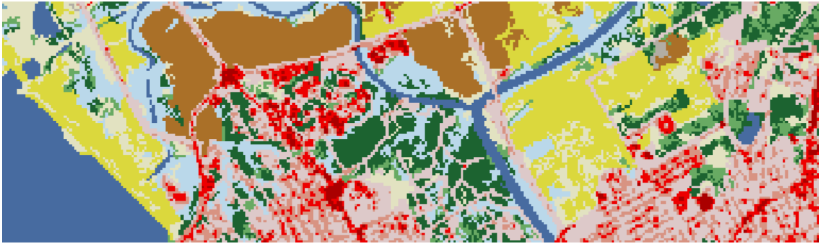
conceptual vs. user view

Next steps

Finish r.futures.demans and r.futures.potential

More documentation needed:

- tutorial
- sample dataset – Raleigh for consistency with GRASS GIS North Carolina sample dataset
    - use publicly available data (National Land Cover Database)



NLCD 2011

What do I need to run it?

1. Gather data (historical urban development, population projection, predictors)
2. Use a high-end workstation
3. Installation is simple, works on all platforms:

```
> g.extension r.futures
```

Code available online:

`trac.osgeo.org/grass/browser/grass-addons/grass7/raster/r.futures/`

Take home message

1. Integrate your work into FOSS
2. Automate tasks
3. Document!

Thank you!

Contact: `akratoc@ncsu.edu`

References

Meentemeyer, R. K., Tang, W., Dorning, M. A., Vogler, J. B., Cunniffe, N. J., & Shoemaker, D. A. (2013)
FUTURES: Multilevel Simulations of Emerging Urban–Rural Landscape Structure Using a Stochastic Patch-Growing Algorithm
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Dorning, M. A., Koch, J., Shoemaker, D. A., & Meentemeyer, R. K. (2015)
Simulating urbanization scenarios reveals tradeoffs between conservation planning strategies
Landscape and Urban Planning, 136, 28–39.