# Bringing declarative programming to Life

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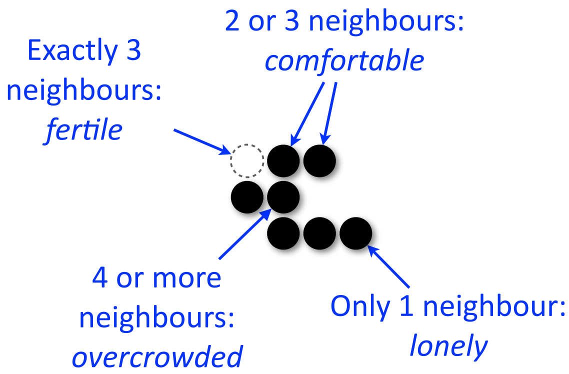
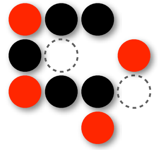
## The game of Life



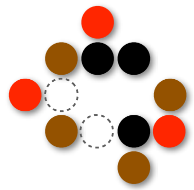



## The next generation …





## … and another one



# Life in the Wolfram language

"In three lines of code"

```
gameOfLife = {224, {2, {{2, 2, 2}, {2, 1, 2},
   {2, 2, 2}}}, {1, 1}};

board = RandomInteger[1, {50, 50}];

Dynamic[ArrayPlot[board = Last[CellularAutomaton
   [gameOfLife, board, {{0, 1}}]]]]
```



# Let's make our own!

One step at a time:

```
for t in range(0, 1000):
   # Compute the next generation
```



# Let's make our own!

Update each cell:

```
for t in range(0, 1000):
   for x in range(0, N):
      for y in range(0, N):
         # Count the live neighbours
         # Update cell[x][y]
```



# Let's make our own!

Visiting the neighbours:

```
for t in range(0, 1000):
   for x in range(0, N):
      for y in range(0, N):
         score = 0
         for i in [-1, 0, 1]:
            for j in [-1, 0, 1]:
               if i <> 0 or j <> 0:
                  score += cell[x+i][y+j]
         score += cell[x][y]/2.0
         ...
```

# Let's make our own!

Updating the cell:

```
for t in range(0, 1000):
   for x in range(0, N):
      for y in range(0, N):
         # Compute the score
         ...
         cell[x][y] =
            (score > 2 and score < 4)
```

**A horrendous bug!**



# Try again!

The rules:

- Don't write functions longer than three lines.
- Don't use assignable variables.
- But do use predefined functions if they are *generally useful*.

I will use the language of GeomLab, but we could use Haskell, or at a pinch Python.



# The master plan

Define a function *next*(*state*) that takes one state of the world and returns the next one.

Begin with an initial state *init*.

Then the Life history is

[*init*, *next*(*init*), *next*(*next*(*init*)), ... ]

going on as long as we want.



# Using *repeat*

Suppose *repeat*(*n*, *f*, *x*) = [*x*, *f*(*x*), *f*(*f*(*x*)), ..., $f^{n}(x)$]:

*repeat*(10, (+2), 3) =
[3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23].

Then the Life history is (say)

*repeat*(200, *next*, *init*).

We'll represent states by images, with pixels made from colours.

# Working with colours

GeomLab has a few predefined colours:

*black*, *white*, *red*.

But other colours can be made as

*rgb*(*r*, *g*, *b*),

where $0 \le r \le 1$, $0 \le g \le 1$, $0 \le b \le 1$.



# Working with images

An image *img* is a rectangular array of pixels.

So we can ask

*width*(*img*), *height*(*img*),

and if [*x*, *y*] are coordinates, we can ask

*pixel*(*img*, [*x*, *y*])

for the colour at that point.



# Making new images

Suppose *f* is a function such that *f*([*x*, *y*]) is a colour:
then *image*(*w*, *h*, *f*) is a $w \times h$ image *img* defined by

*pixel*(*img*, [*x*, *y*]) = *f*([*x*, *y*]).

This is a completely new image, not an image got by modifying an old one.

Is that going to be too inefficient?
Let's try it and see!



# World states as images

The initial state has black pixels in carefully chosen places.

**define** *init* =
  **let** *c* = [[6,2], [7,3], ...] **in**
  *image*(*N*, *N*, **function** (*p*)
    **if** *member*(*p*, *c*) **then** *black* **else** *white*)

# Making the state visible

Replace each pixel with a coloured blob:

```
define blobify(img) =
    above([ beside([ pixel(img, [x,y])
                | x ← [0..width(img)-1] ])
                | y ← reverse([0..height(img)-1]) ])
```

This arranges the blobs in a rectangular array to match the image.



# The next-state function

To get the next state, make a *completely new* image showing the cells that are *viable* in this one.

```
define next(state) =
    image(N, N, function (p)
        if viable(p, state) then black else white)
```



# Which cells are viable?

As before, we must count the neighbours

```
define viable(p, state) =
    let val(q) = if pixel(state, q) <> white then 1 else 0 in
    let s = sum([ val(q) | q ← region(p) ]) + val(p)/2 in
    s > 2 and s < 4

define region([x, y]) =
    [ [u, v] | u ← [x-1 .. x+1], v ← [y-1 .. y+1]
                                    when u <> x or v <> y ]
```

(This time we can describe the neighbours separately.) ▶



# Interactive images

To show the evolution of Life, we must be able to make a picture that depends on time.

```
slide(function (t) rgb(1-t, 0, t))
```

▶

For an animation that has a list of frames:

```
define animate(frames) =
    let n = length(frames) in
    slide(function (t) nth(int((n-0.001)*t, frames));
```

(The 0.001 ensures we don't fall off the end of the film.)

# Putting it all together

Make a list of states, turn each one into a picture, then show the pictures as a slider-controlled animation.

> **let** *life* = *map*(*blobify*, *repeat*(200, *next*, *init*)) **in** *animate*(*life*)

A program built from independent, reusable components – in one line of code!



# Functional programming

- No 'programming' variables – use mathematical variables instead.
- No loop commands – use recursion instead.

Two benefits:

- Easier to make programs from independent pieces.
- Easier to reason about them mathematically.



# Abstract data types

Sets of values (like our images) with operations defined on them.

- The operations obey rules that can be described algebraically. For example,

  $$pixel(image(w, h, f), p) = f(p)$$

- The computer representation of values is hidden.



# The GeomLab site

`http://www.cs.ox.ac.uk/geomlab`

The software:

- runs from the web page (if you're lucky).
- Java-based – no installation required.
- works perfectly on Raspberry Pi.

Teaching materials:

- full set of worksheets for a 1-2 day activity.