Cellular Automata Models of Excitable Media & Cardiac Tissue

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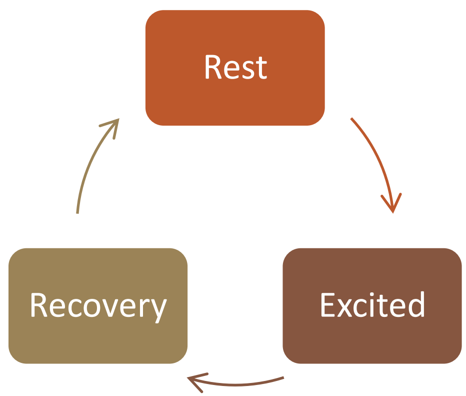
Excitable Systems

An excitable system is a system which has three broad states:

- Rest state
- Excited state
- Refractory or recovery state

When at rest, the system can become excited through a *suprathreshold* stimulation.

The system will then transition, after some time, to the recovery state and then, after more time, back to the rest state.



Excitable Media

An excitable medium is an *excitable system* which has the capacity to propagate a wave until a *certain amount of time (recovery time)* has passed.

The excitable medium cannot pass another wave until the recovery time has passed.

Examples of Excitable Media

- forest / grass fires
- some chemical reactions (e.g. Belousov–Zhabotinsky reaction)
- neurons and nerve fibres (axons)
- cardiac tissue

Modelling Excitable Media

Possibly the simplest model of an excitable medium is a CA where each cell can take one of three values:

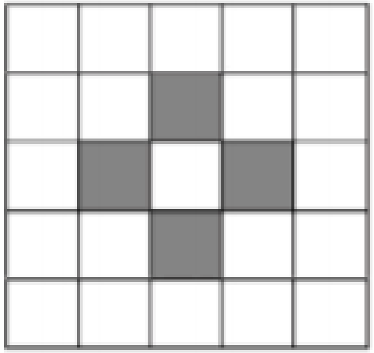
- 0 - resting
- 2 - excited
- 1 - recovering

Simple CA Rules

Each cell has four neighbourhood cells.

Rules for updating the states of cells:

1. A cell moves from state 0 to state 2 at the next time-step (iteration) if at least one of its four neighbours is in state 2.
2. A cell in state 2 transitions to state 1 at the next time-step.
3. A cell in state 1 transitions to state 0 at the next time-step.



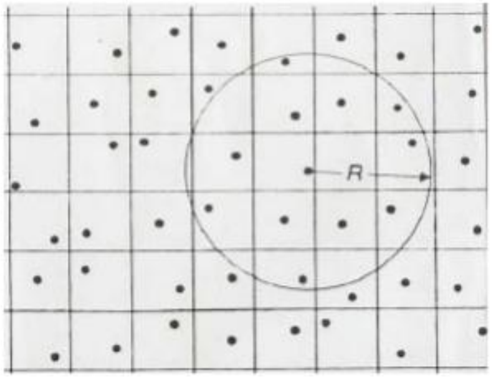
Gerhard, Schuster & Tyson CA

Gerhard, Schuster & Tyson introduced a more realistic model where each cell's state consists of the values of two variables:

u - which can have values 0 (unexcited) or 1 (excited)

v - which has a value in the range 0 (resting) to V_{max} (fully refractory or fully unexcitable).

Each cell has a square neighbourhood of 'radius' r.



Gerhard CA Rules

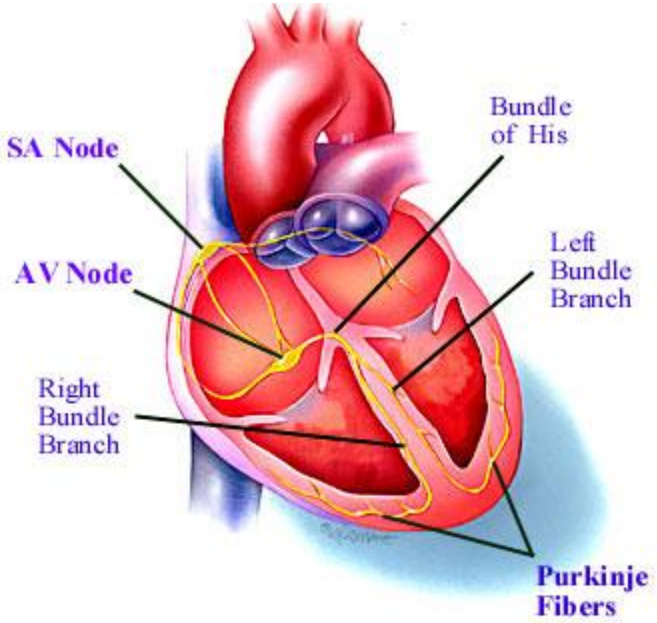
Rules for updating the states of cells:

1. A resting cell (u = 0, v near to 0) can be excited (u becomes 1) if a sufficient number of cells (k_{exci}) in its neighbourhood are excited.
2. Each timestep an excited cell's v variable increases by g_{up}.
3. When v reaches V_{max} the cell becomes unexcited (u becomes 0).
4. Each timestep an unexcited cell's v variable decreases by g_{down}.

The heart's electrical system

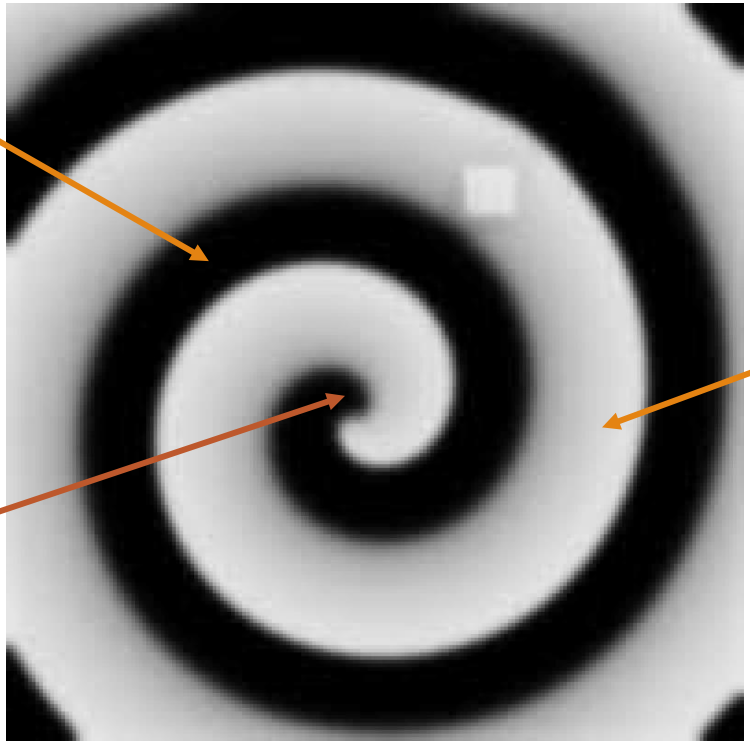
Contraction of heart muscle is due to electrical waves.

Breakdown of cardiac rhythm is a major cause of death — modelling is important!



Model behaviour

Spiral waves simulates how the electric signals stimulate the heart cells.



Further Reading

Gerhardt M, Schuster H, Tyson JJ. *A cellular automation model of excitable media including curvature and dispersion*. Science. 1990 Mar 30;247(4950):1563-6.