EstSim: Simulation rationale

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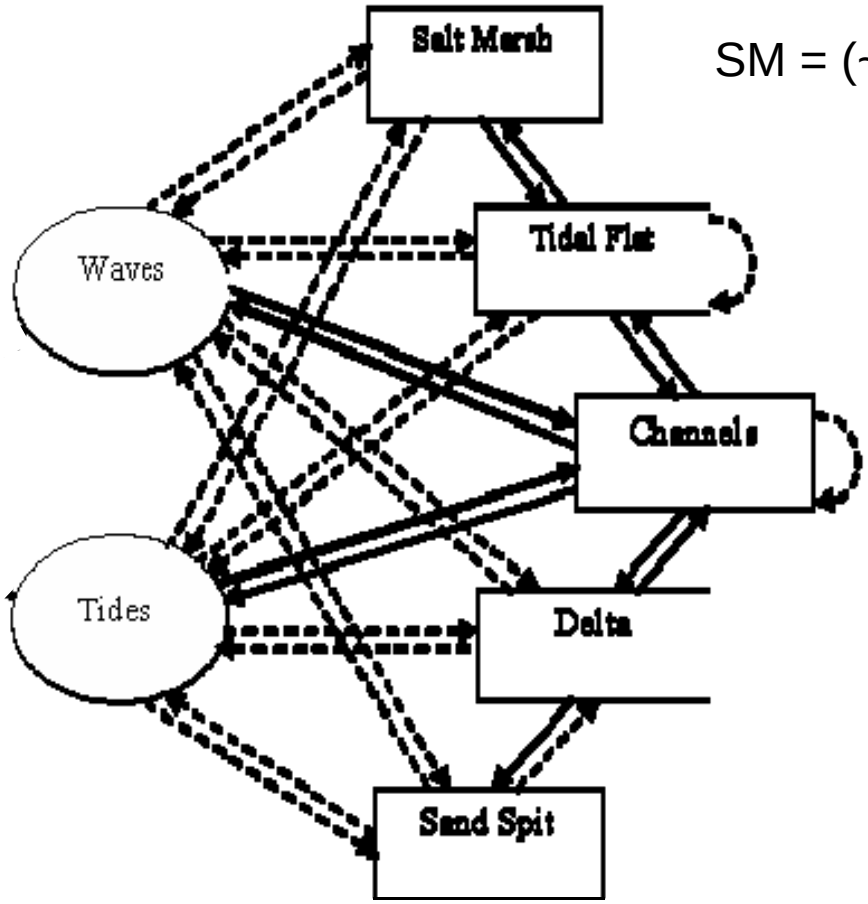
Complex geomorphic systems

- Functional relationships between morphological components and processes cannot always be mathematically specified in physically realistic way
- Estuaries may be in meta-stable state where constraints prevent evolution to alluvial equilibrium morphology
- Qualitative modelling offers a means of formalising weakly-quantified geomorphological knowledge to provide indicative insights into long-term morphological behaviour

Qualitative modelling approaches

- Qualitative Reasoning – used in AI (e.g. robotics and mechanical systems for which governing equations known but data lacking)
- Causal Loop analysis – used in OR (e.g. management of business organisations), possibly as prelude to ‘stock & flow’ model (e.g. using *Stella*)
- Network-based models – inference from system structure (e.g. gene networks, WWW)

Boolean network model concept
(after Karunarathna and Reeve, 2005)



SM = (~w & t & tf)

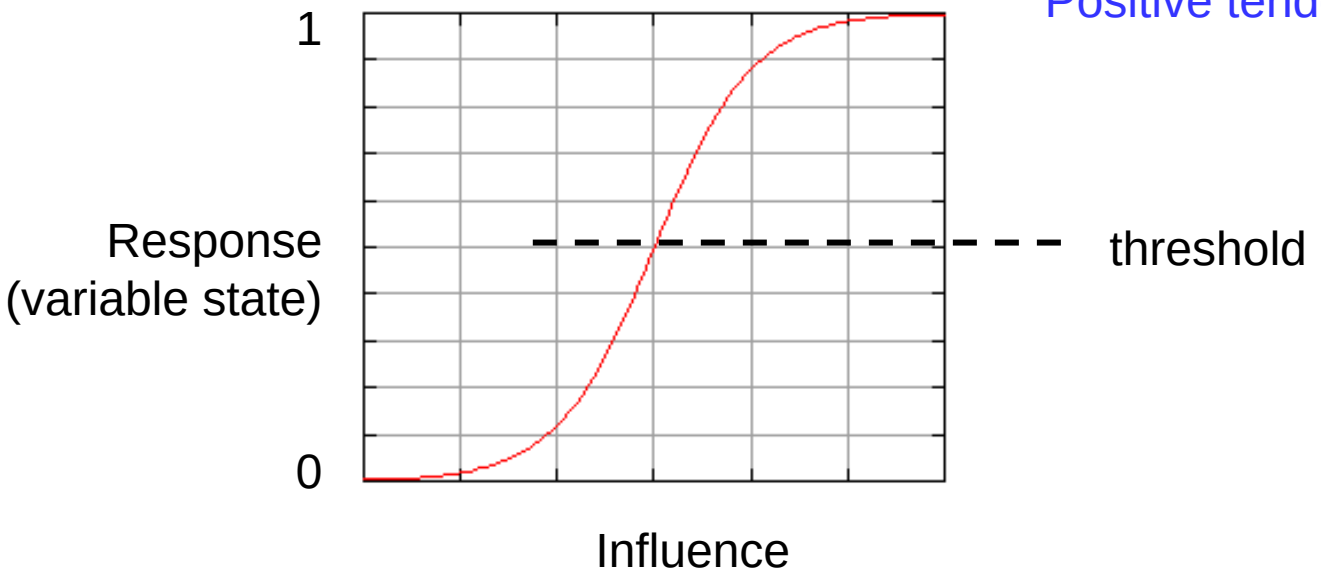
CC = (w | t) & (tf | dd) | ~cc

Logical operators:

AND	**&**
NOT	**~**
OR	**|**

Boolean variables

‘Present’
‘Significant presence’
‘Positive tendency’



‘Absent’
‘Negligible presence’
‘Negative tendency’

Boolean (logical) operators

INPUT		OUTPUT
A	B	A **AND** B
0	0	0
0	1	0
1	0	0
1	1	1

INPUT		OUTPUT
A	B	A **OR** B
0	0	0
0	1	1
1	0	1
1	1	1

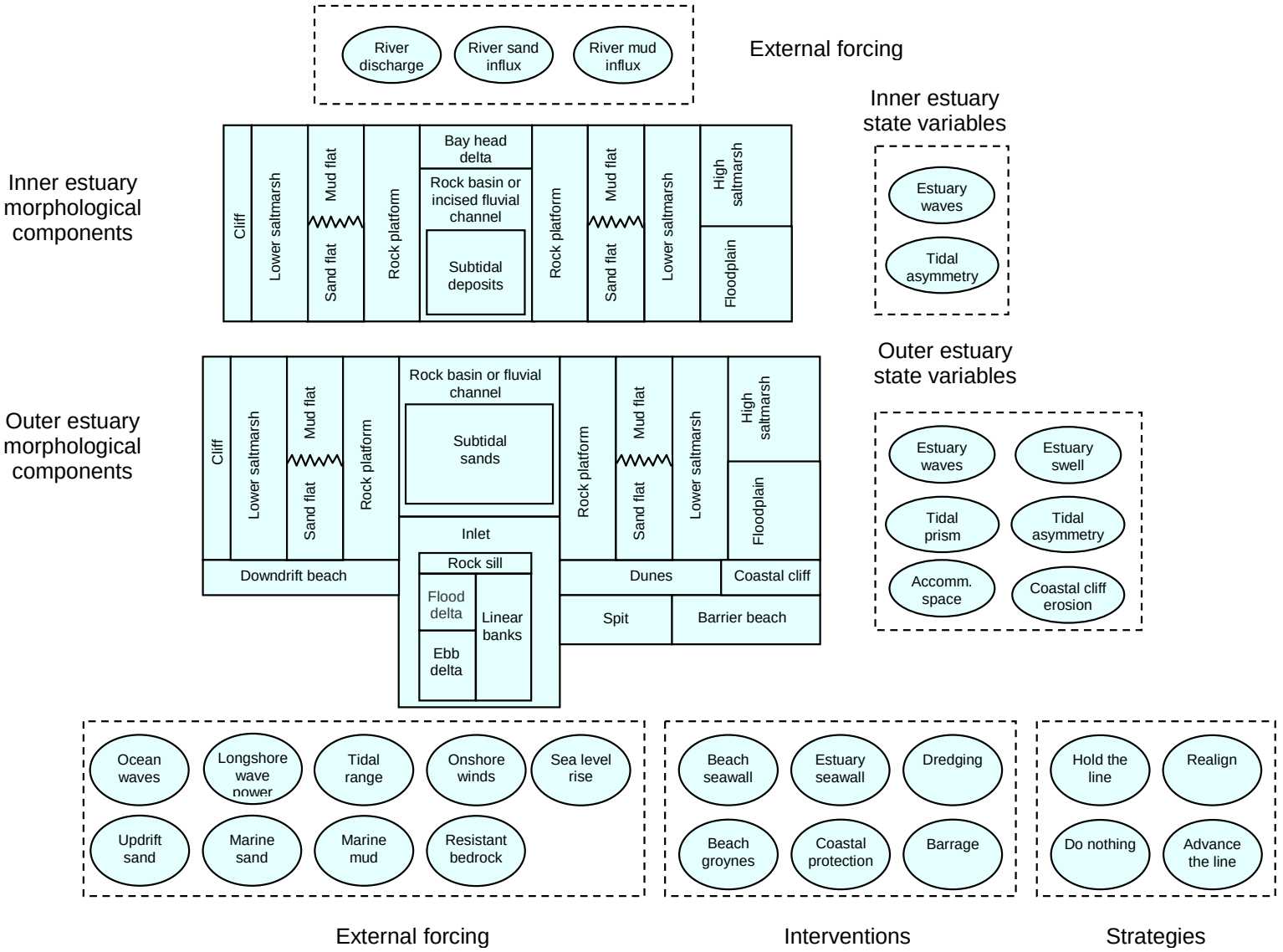
INPUT	OUTPUT
A	**NOT** A
0	1
1	0

Truth tables for AND, OR, NOT

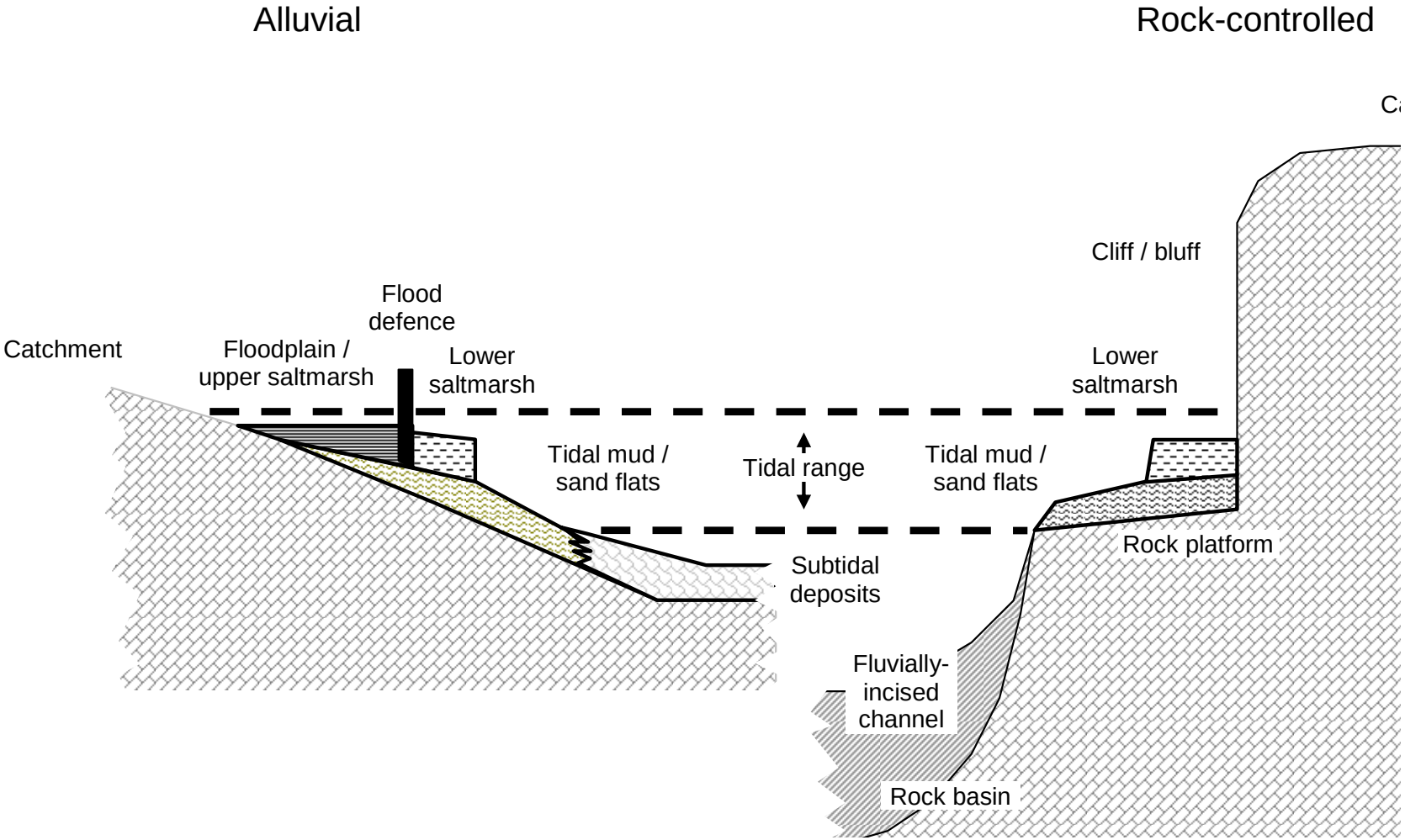
How do we run this model?

- Identify variables and define functions
- Specify initial states (0, 1 or ‘off’, ‘on’)
- Compute all functions and reset variables to value given by function
- Repeat until
  - No change (steady state)
  - Repeating cycle (oscillatory state)

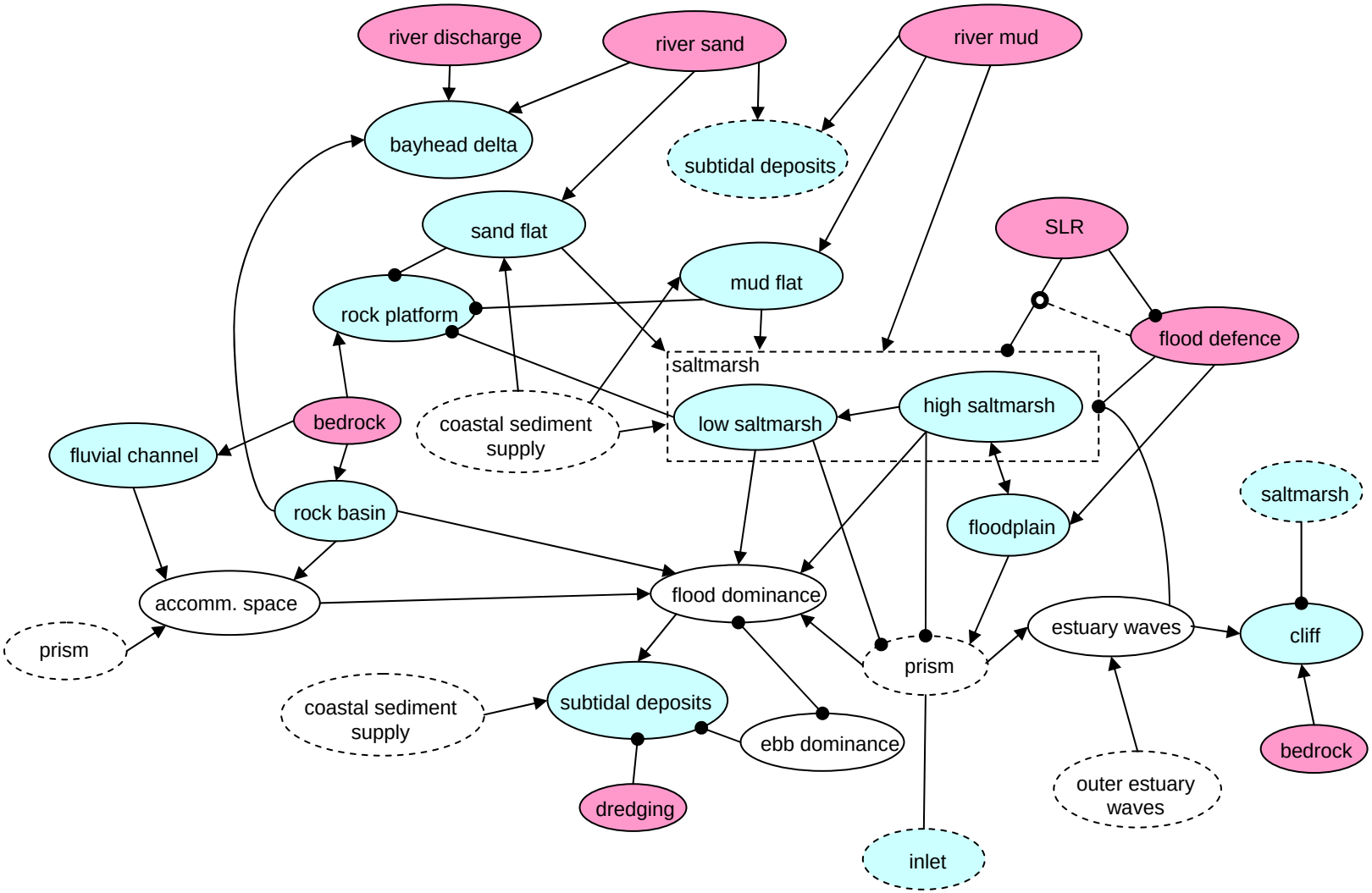
EstSim variable set



EstSim stratigraphic framework



Influence diagram, inner estuary



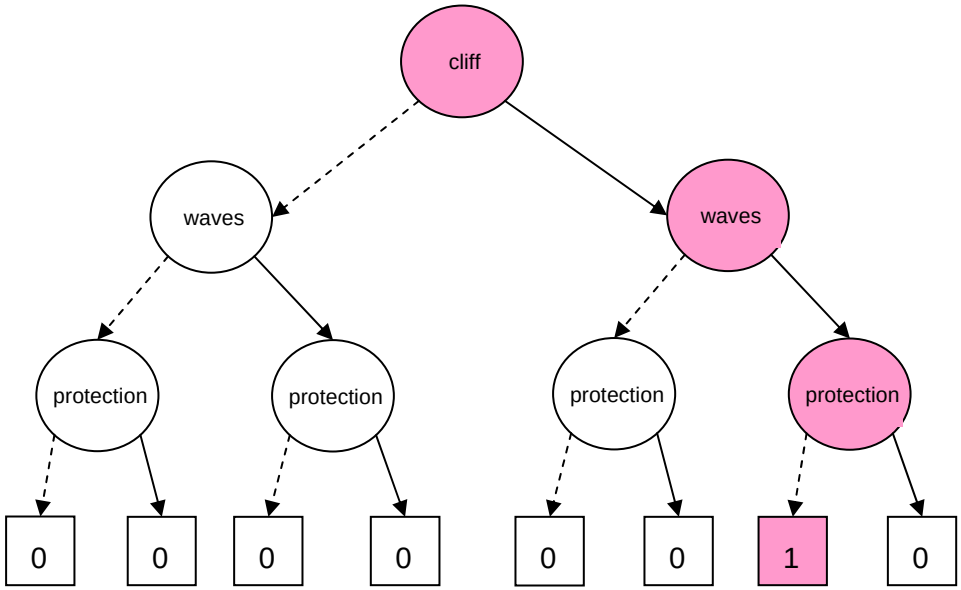
Knowledge formalisation: simple example of coastal cliff erosion

Qualitative reasoning

Coastal cliff erosion requires presence of both cliff and significant wave action but erosion ceases with cliff toe protection

Boolean function

CLIFF_EROSION = cliff AND waves AND (NOT protection)



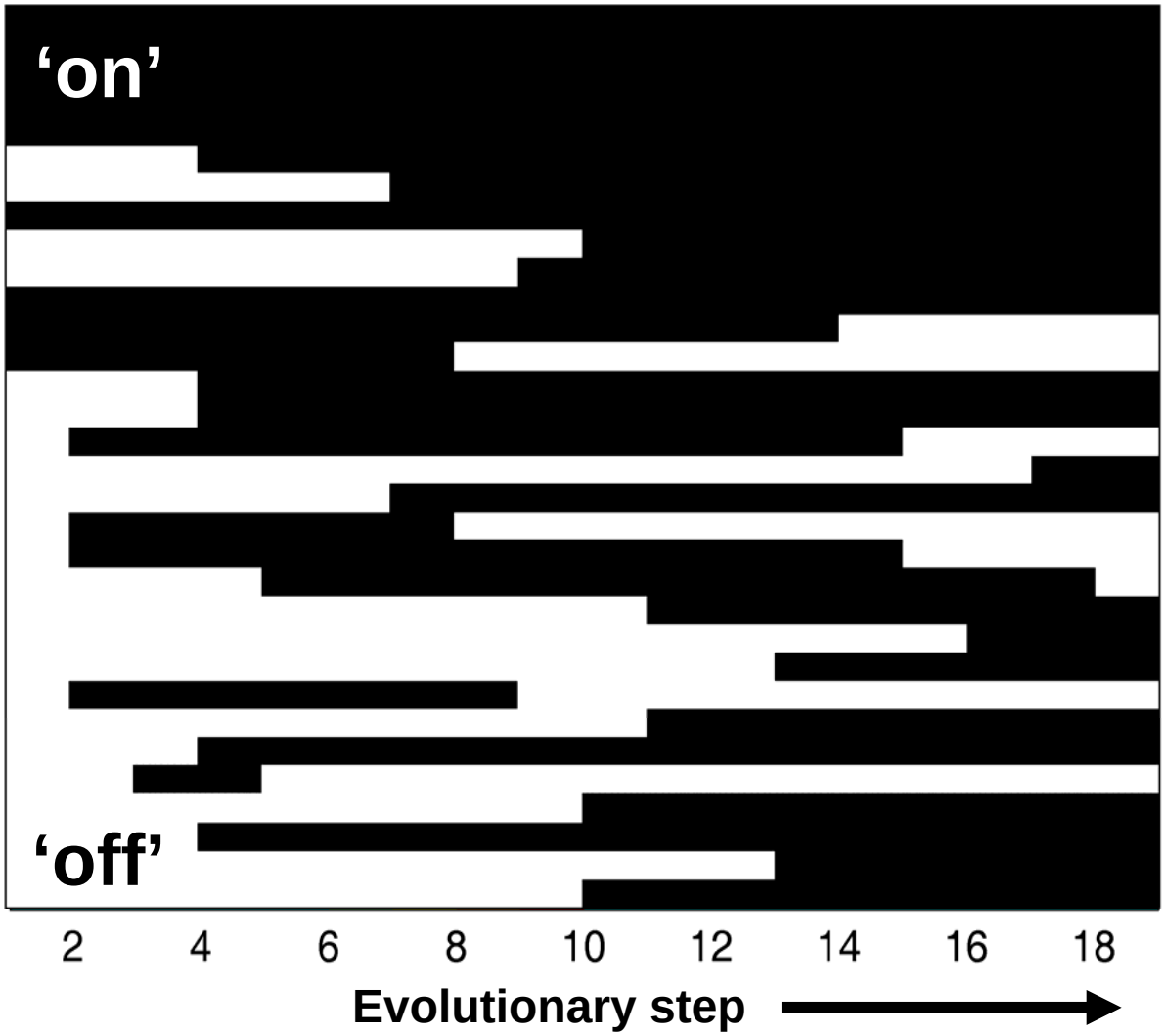
Decision tree

Time evolution of morphology

- Variable states updated synchronously
  - Fixed ‘timestep’
  - No absolute timescale assigned
- Morphological response lags process forcing
  - Process must be sustained to effect change
  - ‘Rapid’ elements (e.g. beach)
  - ‘Slow’ elements (e.g. saltmarsh)
- Endpoints (equilibria) easier to interpret than intermediate steps

Example: evolution of tidal inlet

ocean_waves
longshore_power
littoral_sand
marine_sand
marine_mud
mesotidal
updrift_beach
spit
inlet
downdrift_beach
dunes
wind
prism
accomm_space
ebb_delta
flood_delta
outer_flood_dominance
outer_ebb_dominance
outer_subtidal_sands
outer_estuary_swell
outer_estuarywaves
outer_sandflat
outer_mudflat
outer_marsh_low
outer_marsh_high
outer_floodplain
inner_flood_dominance
inner_ebb_dominance
inner_estuarywaves
inner_sandflat
inner_mudflat
inner_marsh_low
inner_marsh_high



How can we use this model?

- Generic estuary behaviour
  - Fjords, Fjards, Ria, Spit-enclosed, Funnel-shaped, Embayment, Tidal inlets (FD2117 UK classification)
  - Can we predict equilibrium morphology from forcing / constraints? … yes
- Case studies and scenarios
  - Can we replicate historic behaviour (e.g. Ribble, Southampton Water)? … broadly, yes
  - Can we predict indicative responses to imposed change? … in general terms; generic templates require customisation

Delivery

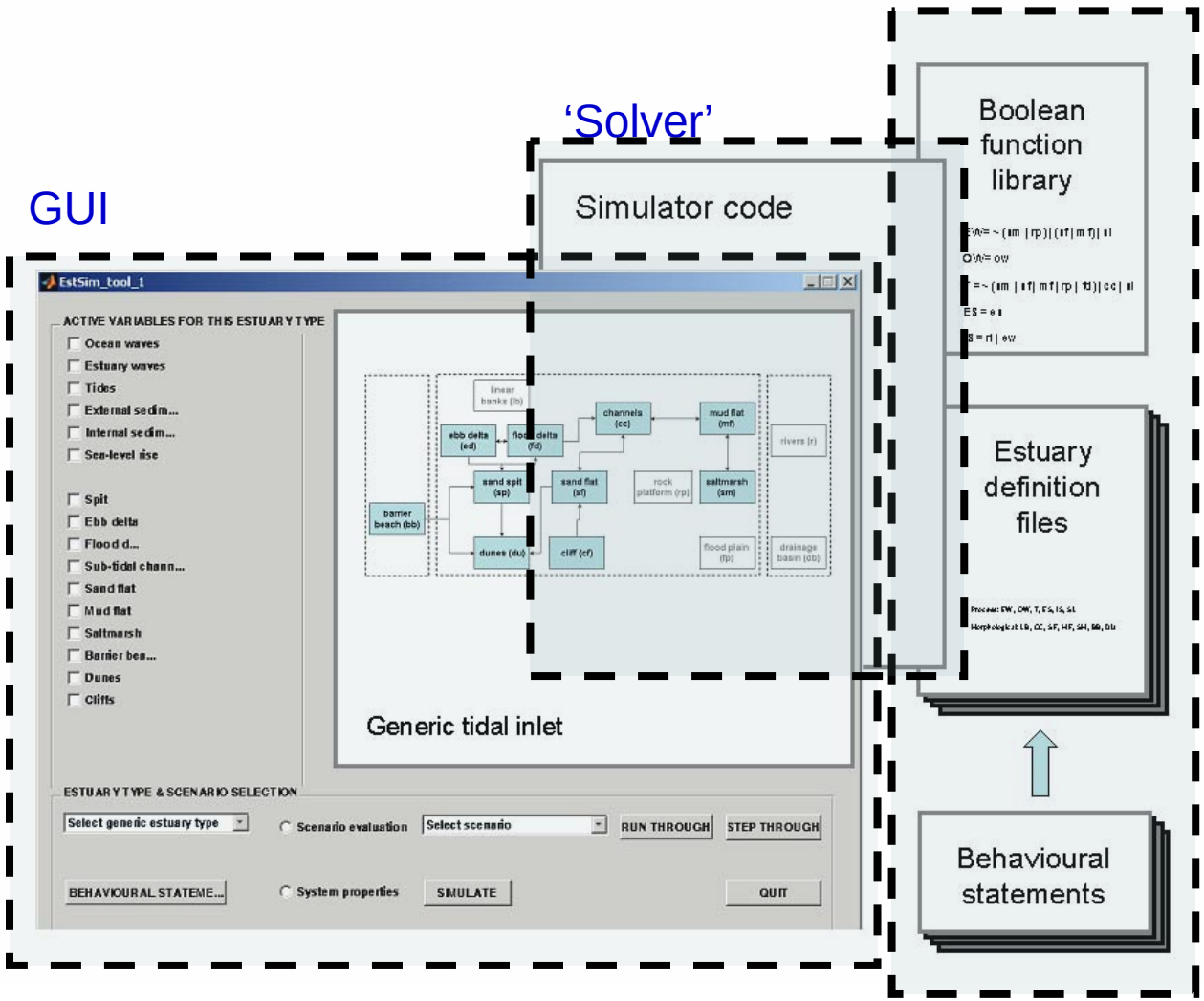
- Web-based demonstration tool
  - Adobe Flash application with GUI

    www.discoverysoftware.co.uk

- Open-source research code
  - Matlab code, generic function libraries
  - Less sophisticated GUI

    www.geog.ucl.ac.uk/ceru/estsim

Simulator architecture



Key findings and issues

- Computationally simple and fast to execute (seconds)
- Infinitely customisable without any re-coding of solver … prototype is just a starting point
- "I don't like the geomorphological rules!" … highly generic rules for proof of concept – easy to customise and evaluate alternative views
- Geomorphological formalisation hard … more variables / sub-systems
- No explicit timescale … could explore more complete Boolean delay equation model (non-synchronous; specified timescales)
- Binary representation restrictive … other mathematical formulations possible and could use same basic simulator architecture

Conclusions

- First-ever application of Boolean networks to geomorphological systems
- Able to simulate whole-estuary behaviour (and estuary-coast interaction) from qualitative knowledge of system components
- Limited ability to resolve detail, but possible to extend methodology and explore alternative mathematical formulations
- We have only scratched the surface of what is possible with this kind of qualitative model