A Modelling and Simulation Tool for DNA Strand Displacement Systems

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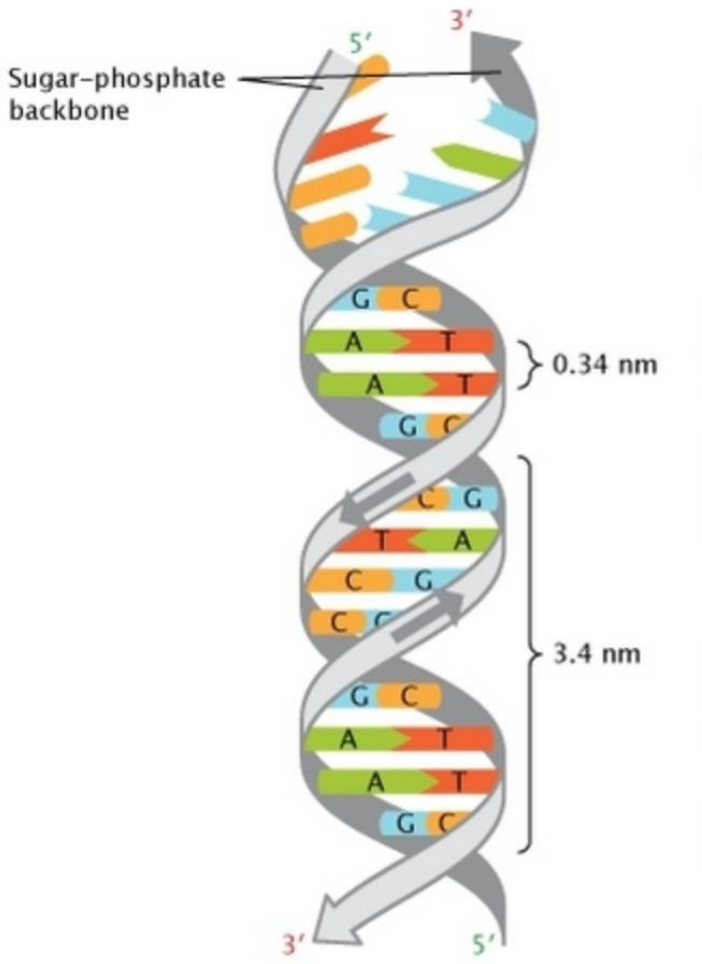
Funded by the European Union

AQTIVATE

The *AQTIVATE* project receives funding from the European Union's HORIZON MSCA Doctoral Networks programme, under Grant Agreement No. 101072344.

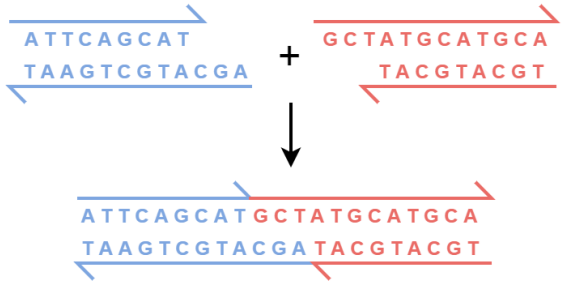
Background: DNA

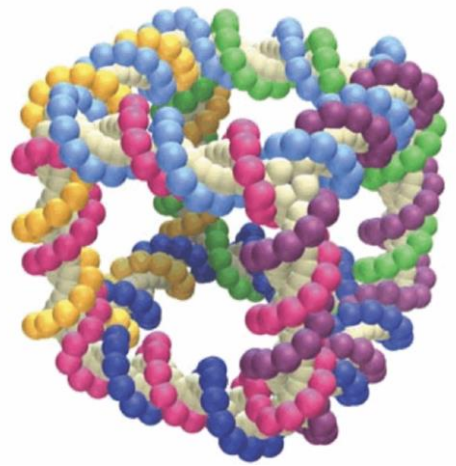
- Has a double helix structure.
- The two strands are antiparallel.
- Follows a base pairing rule.



Background: Structural DNA Nanotechnology

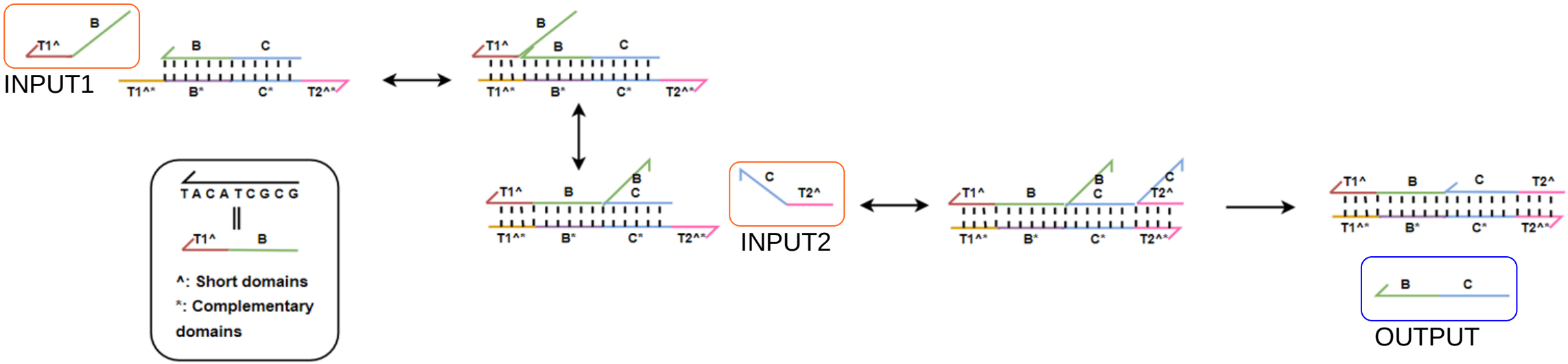
Method: Self Assembly





Background: Dynamic DNA Nanotechnology

Method: DNA Strand Displacement (DSD)



DSD Modelling

Challenges:

1. Design a DSD system by hand may be exhaustive.
2. Existing DSD modelling tools face:

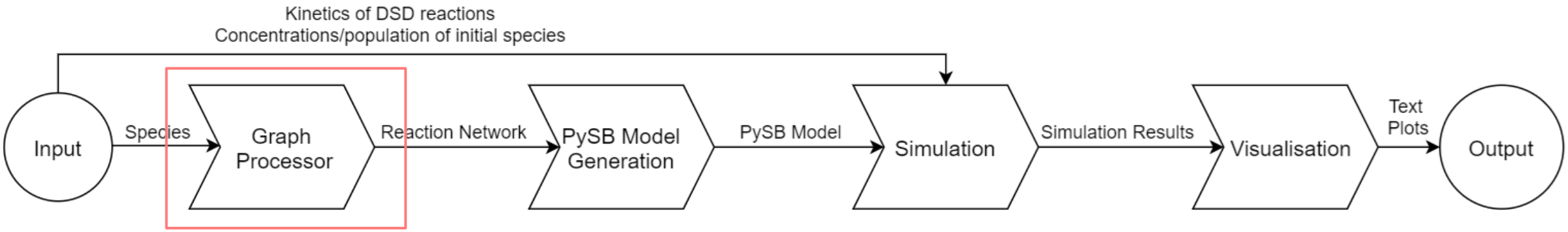
   1) Difficulty with representing secondary structures.

   2) Possible computational infeasibility.

Possible Solution:

1. An automated tool that generates and simulates DSD systems.
2. A tool that can represent DNA secondary structures and provide a solution for intractable reaction networks.

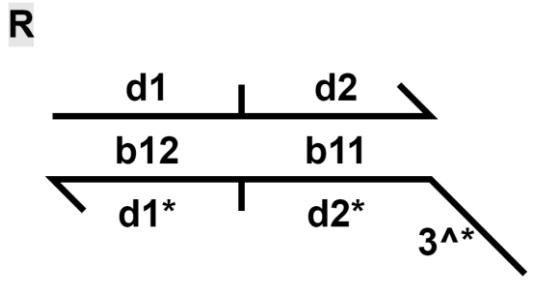
The RuleDSD Pipeline



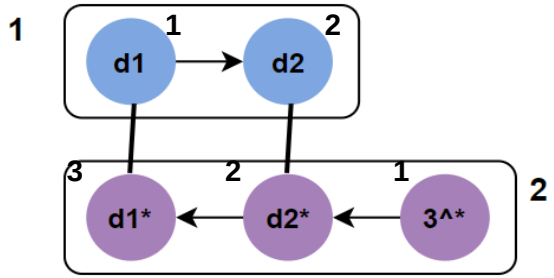
DSDPy

1. generates graph representation of species (DNA complexes).
2. applies interaction rules (DSD reactions) to species.
3. produces reaction network of interactions.

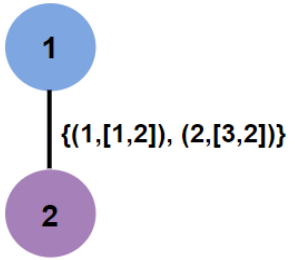
Representations of Species



Species Drawing



Strand Graph



Bond Graph

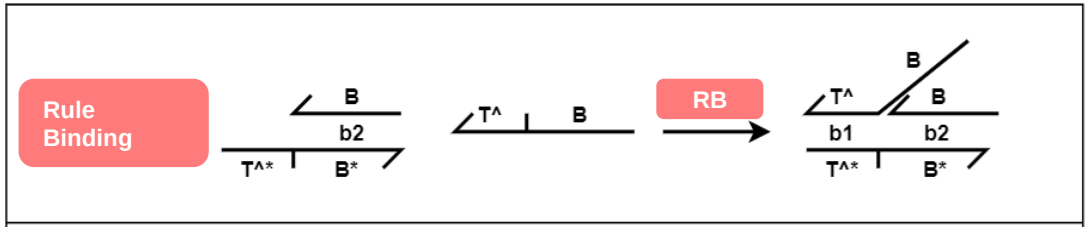
<d1!1 d2!2>
<3^* d2*!2 d1*!1>

Labelling of Strand Graph (Textual Representation)

DSD Reactions

Four types of reactions:

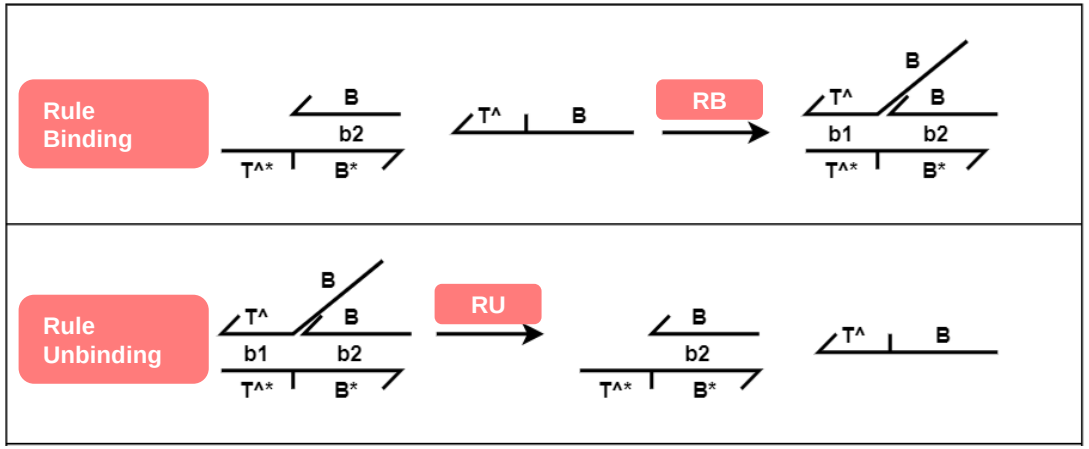
1. Binding



DSD Reactions

Four types of reactions:

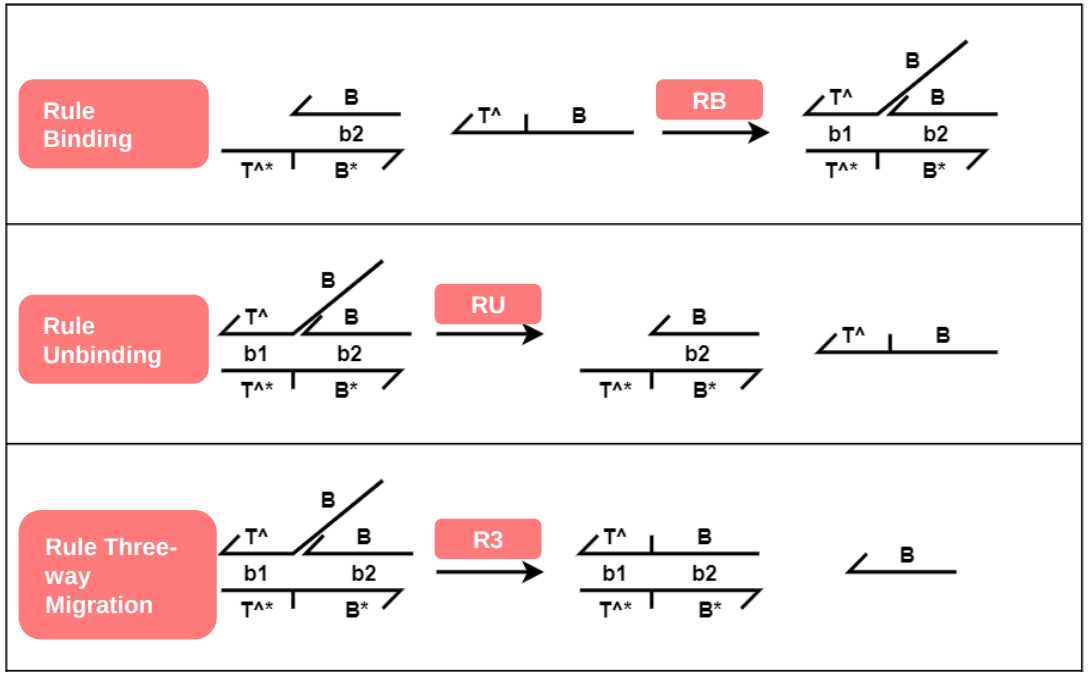
1. Binding
2. Unbinding



DSD Reactions

Four types of reactions:

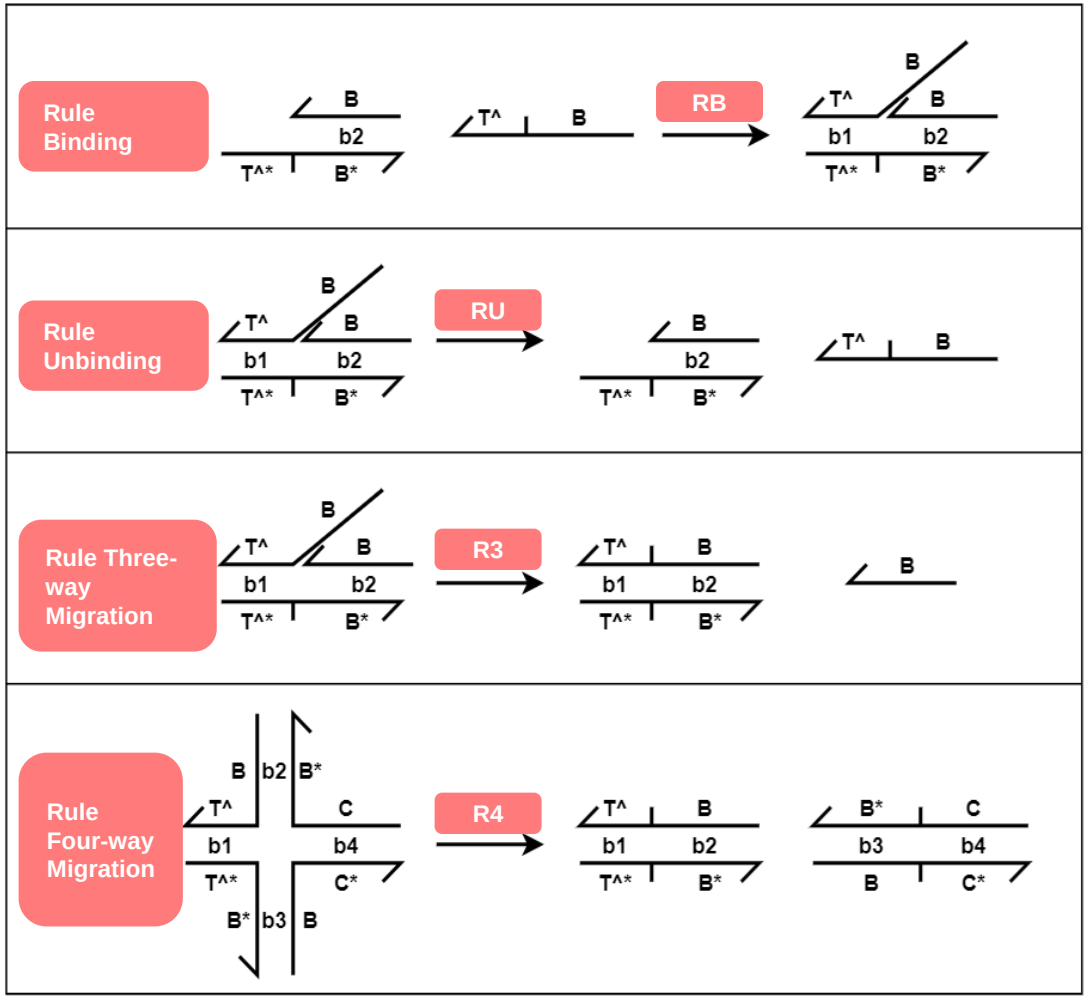
1. Binding
2. Unbinding
3. Three-way Branch Migration



DSD Reactions

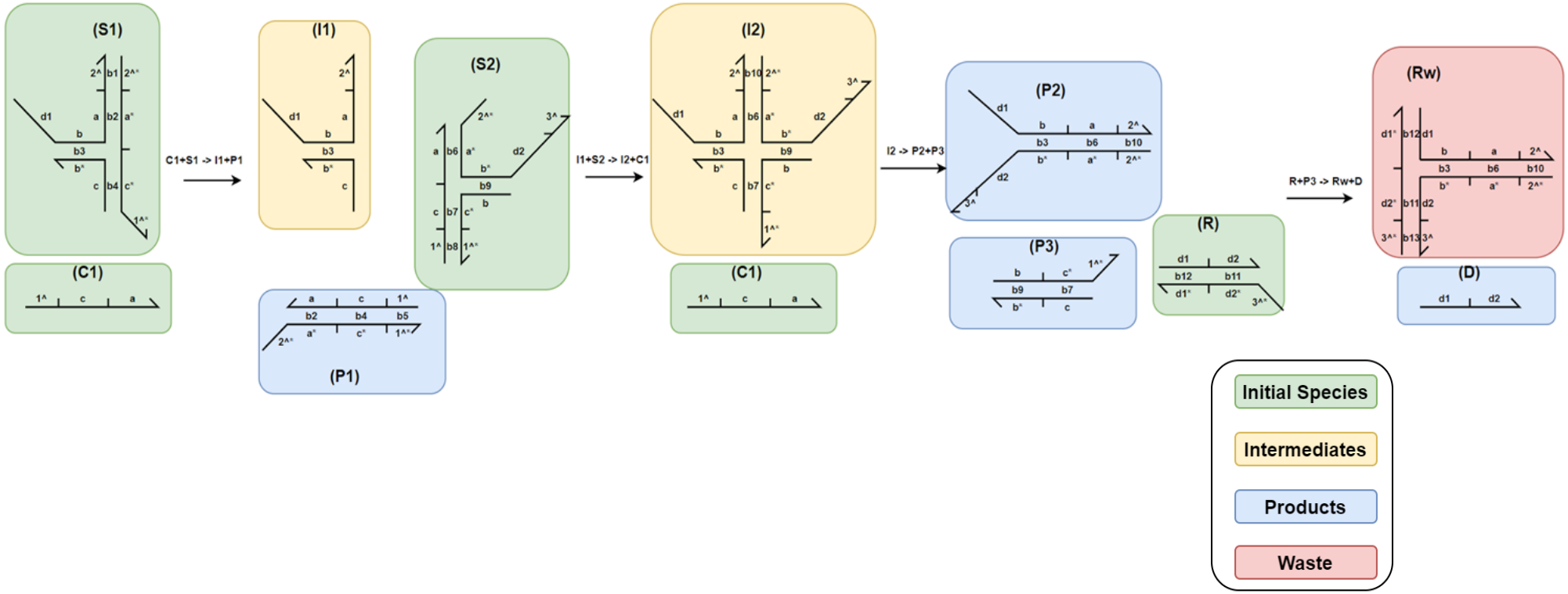
Four types of reactions:

1. Binding
2. Unbinding
3. Three-way Branch Migration
4. Four-way Branch Migration



Reaction Network (1)

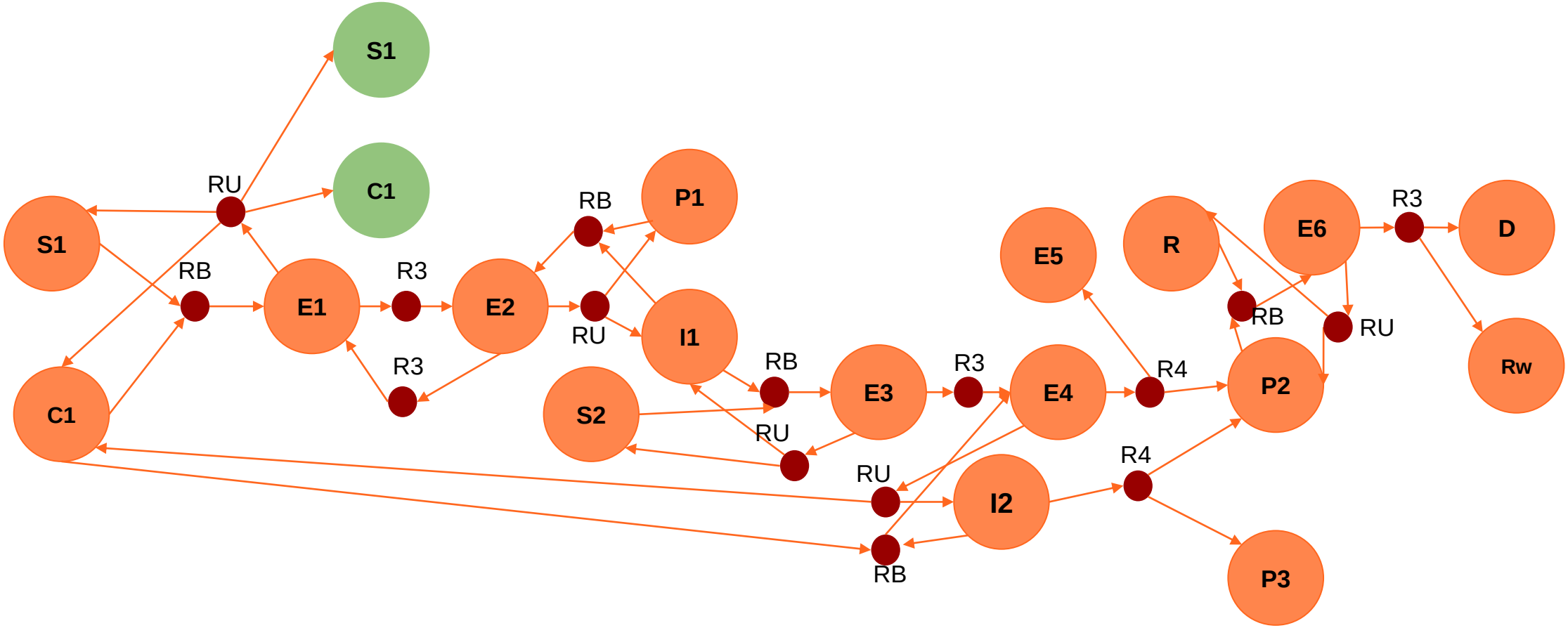
Example: A Single-Layer Catalytic DSD (SCD) System*



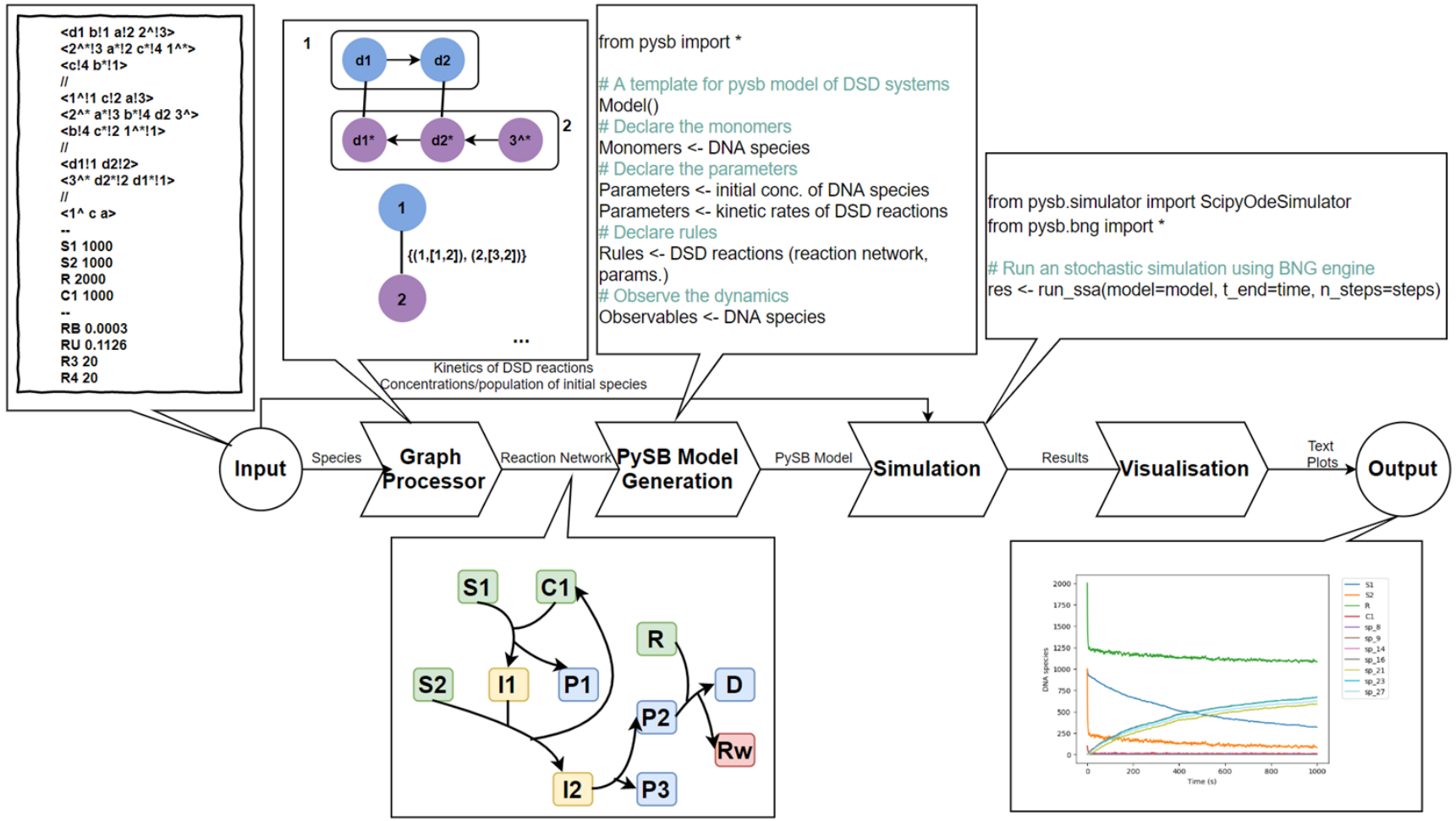
* Kotani, S., and Hughes, W. L. Multi-arm junctions for dynamic DNA nanotechnology. Journal of the American Chemical Society 139, 18 (2017), 6363–6368.

Reaction Network (2)

Combinatorially enumerates all species reachable from the initial species.



The RuleDSD Pipeline



Thank you