Minerals processing: Separation circuits

Background

- Consider the extraction of a mineral from its ore. The impure ore may be passed through a separation unit (e.g. a flotation cell) which attempt to recover the valuable material to a **concentrate stream** and reject the waste material into a **tailings stream**.

- Typically individual separation units are inefficient, in that some proportion of the concentrate stream will still contain waste material, and some of the tailings stream will still contain valuable material. Therefore in order enhance recovery of valuable material and improve the purity of the final product, multiple units can be combined into a separation circuit.

- Circuit design will typically be a compromise between the total mass of valuable material recovered vs the proportion of valuable material in the final product (purity). The optimal circuit will depend on the economic balance between how much you are paid for valuable material with how much you are penalised for lack of purity in the final product.

Modelling a unit

Simplified assumptions:

- There are only two components in the feed ("valuable" material and "waste" material).
- A constant fraction of each component is recovered to each of the streams which is the same for each unit and does not change with the feed rate.
    - X % of the valuable material --> concentrate stream
    - Y % of the waste material --> concentrate stream
    - Remaining material --> tailings stream

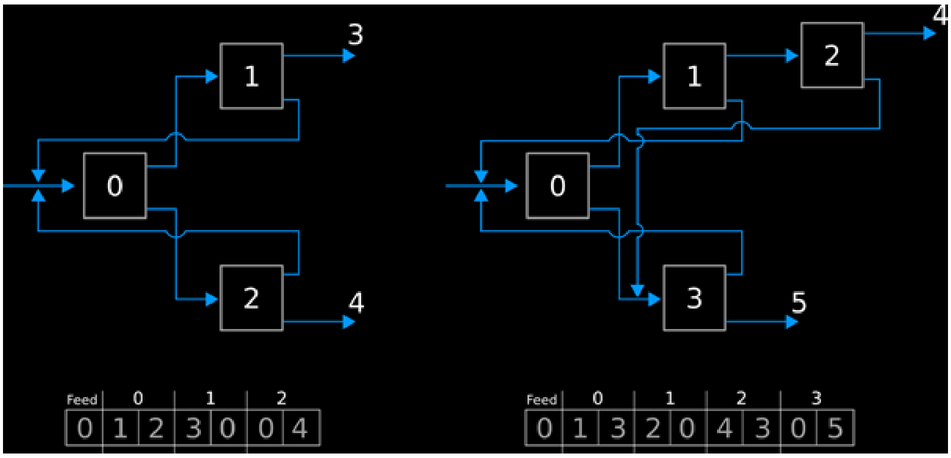
Modelling a circuit

There are three key things to consider:

1. Check the circuit is valid
2. Calculate the flows in all the circuit streams
    - *from modelling individual units*
3. Use product flows to calculate a performance metric

Assume there is a single "feed" stream into the first unit in the circuit, with a constant feed rate of A kg/s of valuable material and B kg/s of waste material.

Each unit can have any number of input streams but only two output streams (concentrate and tailings). A circuit of n units can therefore be represented as a vector of length $2n+1$:



Each element of the circuit vector defines the unit number / index for the destination of the corresponding stream. The unit number is also taken to include the final concentrate or tailings stream (which will have an index *n* and *n+1* respectively). The feed must go into one of the actual units, so the first entry to the vector can be any value between 0 and *n-1*.

Assuming the circuit is in steady state we can calculate the mass flow rate of each component (valuable or waste) into each stream. Steady state implies the total feed into each unit is equal to the sum of the flow out of the unit to the two output streams.

Circuits can perform "recycling" where one or both of the output streams from a unit can feed back into an earlier unit in the circuit. It is therefore simplest to solve for the circuit performance iteratively. It has been proven that ***successive substitution*** of the component mass flows in the streams is guaranteed to converge if a valid solution exists.

Checking circuit validity

The fact that successive substitution is guaranteed to converge if a valid solution exists means that an invalid circuit could be assessed by divergence of the simulation. However, it is cheaper to explicitly check for a valid circuit before running the simulation and only run the simulation if it is valid...

In the context of genetic algorithms, explicitly checking for validity means circuits can efficiently be rejected without being considered for the next generation. Further, ensuring the initial list of parents are all valid circuits will result in much quicker convergence.

For a circuit to be valid a few conditions must be met:

- Every unit must be accessible from the feed, i.e. there must be a route that goes forward from one unit to the next from the feed to every unit
- Every unit must have a route forward to both of the outlet streams. A circuit with no route to any of the outlet streams will result in accumulation and therefore no valid steady state mass balance. If there is a route to only one outlet then the circuit should be able to converge, but there will be one or more units that are not contributing to the separation and could therefore be replaced with a pipe.
- There should be no self-recycle. In other words, no unit should have itself as the destination for either of the two product streams.
- The destination for both products from a unit should not be the same (different) unit.

The circuit takes the form of a directed graph, and therefore can be traversed using recursion to check validity.