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Optimizing observability and redundancy by means of globally optimal measurement selection

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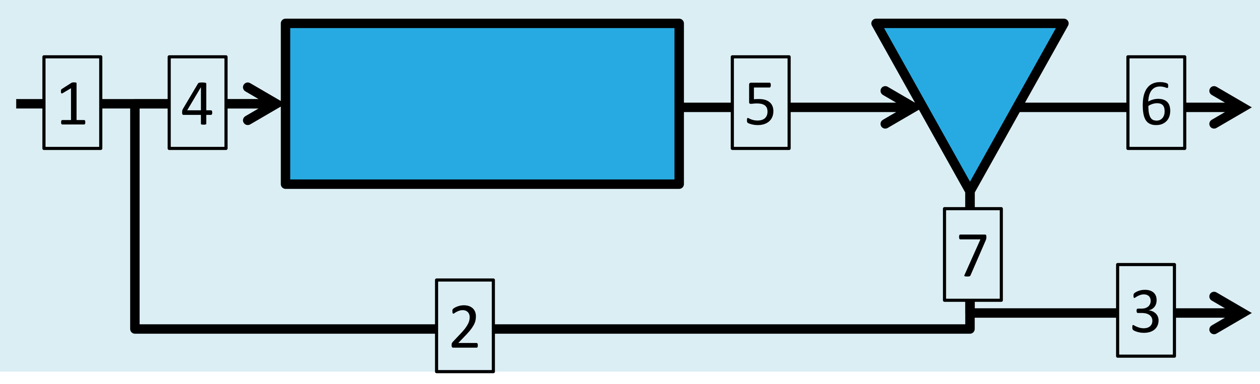
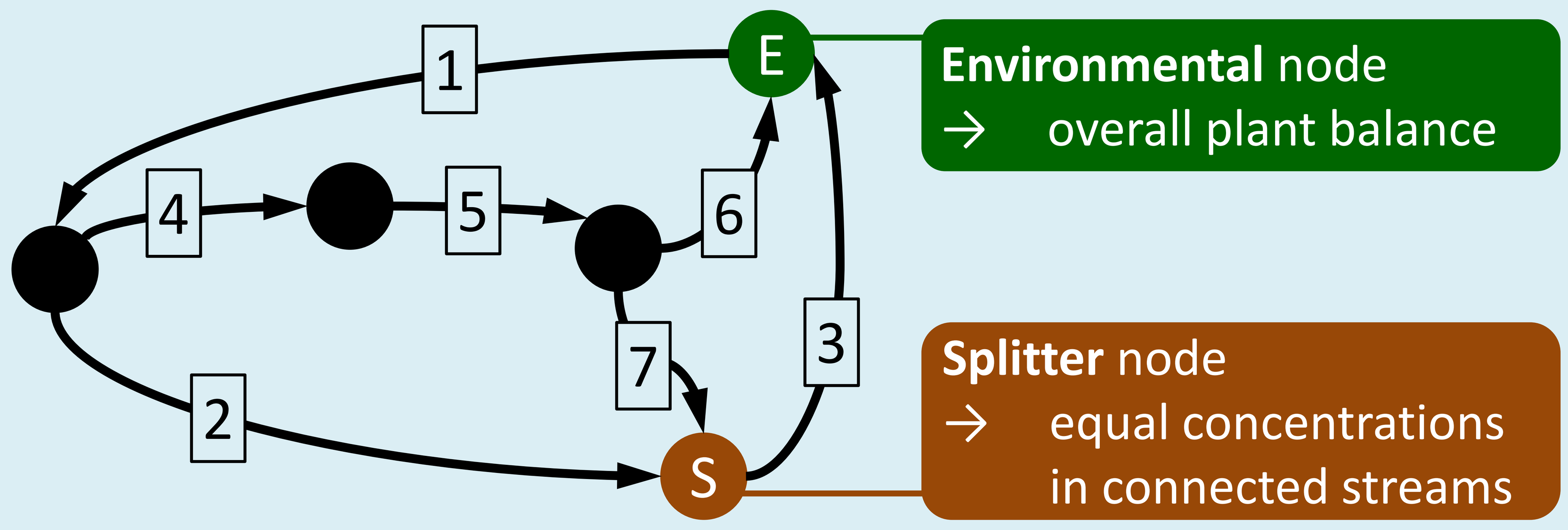
OPTIMIZING SENSOR PLACEMENT?



Conventional display of a small wastewater treatment plant (WWTP)

Problem statement: How should sensors be selected and placed in a WWTP to obtain maximal amounts of information while ensuring that faulty data can be detected automatically?

STEP 1: GRAPH REPRESENTATION



A graph is a mathematical construct with physical junctions and streams defined as nodes and edges.

Theory: Graphs are efficient tools to represent a system in an abstract manner for computer-aided analysis and decision-making. Every node (circle) represents a independent set of balance equations (e.g. flow balances, mass balances).

STEP 2: OBSERVABILITY AND REDUNDANCY

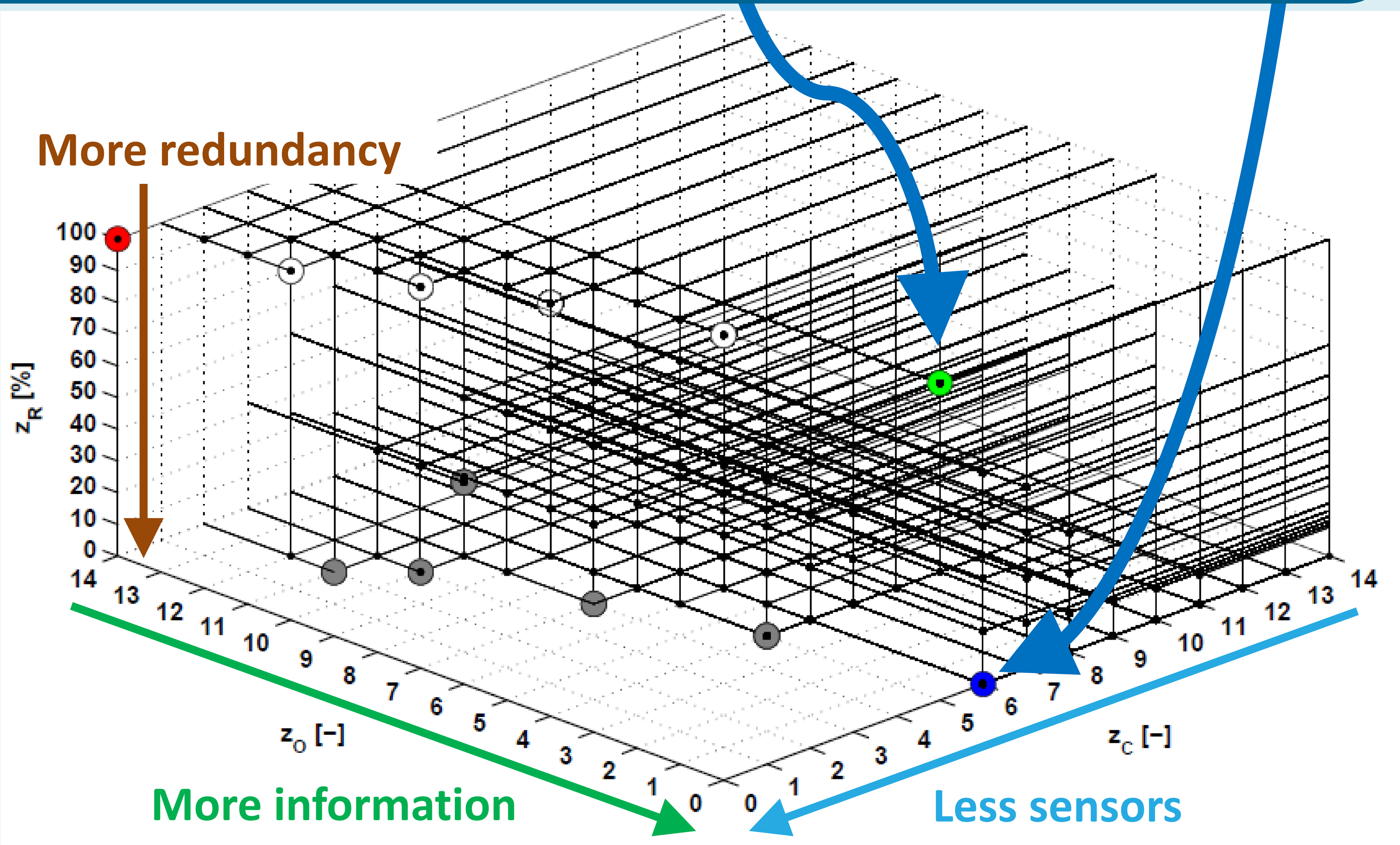
LAYOUT 1	Measurement (Y/N)		Observable (Y/N)		Redundant (Y/N)	
Stream index	Flow rate	TSS	Flow rate	TSS	Flow rate	TSS
1	Y	Y	Y	Y	Y	Y
2	Y	Y	Y	Y	Y	Y
3	N	N	Y	Y		
4	N	N	Y	Y		
5	N	N	Y	Y		
6	Y	N	Y	Y	Y	
7	N	Y	Y	Y		Y

LAYOUT 2	Measurement (Y/N)		Observable (Y/N)		Redundant (Y/N)	
Stream index	Flow rate	TSS	Flow rate	TSS	Flow rate	TSS
1	Y	Y	Y	Y	N	N
2	Y	Y	Y	Y	N	N
3	N	N	Y	Y		
4	N	N	Y	Y		
5	N	N	Y	Y		
6	Y	N	Y	Y	N	
7	N	N	Y	Y		

Graph-based algorithms evaluate structural observability and redundancy

Theory: Graph-based algorithms take structural observability and redundancy into account. This allows to screen for sensor layouts without detailed sensor information (e.g. precision).
A ***variable*** is structurally ***observable*** when measured directly or an estimate is available. A ***sensor*** is structurally ***redundant*** if the variable remains observable when the sensor is removed.
Example: Flow rate and TSS measurements are considered. Results for two feasible sensor placements are shown.

STEP 3: SENSOR LAYOUT OPTIMIZATION



Deterministic globally optimal Pareto front considering the following criteria

1. **Number of sensors (z_C)**
2. **Number of non-observable variables (z_O)**
3. **Fraction of non-redundant sensors (z_R)**

Theory: *Globally optimal solutions are found by means of multi-criteria Integer Programming (IP)*
Example*:* In this small-scale example, the search algorithm
- Explores a space of 16384 = 2^{14} layouts
- Evaluates 8352 sensor layouts explicitly
- Finds 1257 Pareto-optimal solutions
- Finds 12 unique locations on the Pareto front

TAKE HOME MESSAGE

- **Global deterministic optimization schemes help to screen for good sensor layouts**
- **Continued efforts aim at *(i)* scaling up the optimization algorithms to more complex plant layouts, *(ii)* taking reactions and storage phenomena into account, and *(iii)* including practical observability and redundancy criteria**

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