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Mapping the network of industrial processes from a Life Cycle Inventory database

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Life Cycle Inventory (LCI): a few notions
- Flows: litre of fuel, kWh of electricity, ... 
- Industrial processes have in/out flows: \( p = (p_i, p_o) \)
- Process matrix: \( P = (p_i, p_o) \) can be partitioned \( P = \begin{bmatrix} A & B \\ B^T & D \end{bmatrix} \)
- Demand vector \( f \) (\( \{f_i, \ldots f_n\} \))
- The scale vector \( s \) determines total output \( A_s = f \).

What can be done with Life Cycle Inventory (LCI)?
- Solve the inventory problem: if demand \( f \) is fixed, what is \( s \) ?
- Intuition: to/from environment: \( B \).
- CA: contribution analysis. Which processes contribute most to specific environmental input/output ?
- And much more...

LCI vs related fields
- Carbon Footprint.
- Material Flow Analysis MFA (stocks and flows, specific territory).
- IO analysis (industrial sector in/out, monetary, aggregate).
- Trade networks.

Networks and LCI?
- Many measures in LCI/LCA, but topology not involved.
- Wood/Lenzel [3]: "connectivity" measure is a proxy for average path length in IO economic analysis. It is studied across time for the Australian economy and shows increasing complexity.
- Heijungs et al. [2] builds monopartite projections (process/process, flow/process), using Ecoinvent database. Main findings:
  - Sparse, small diameter: "small world".

Dataset
- Agribalyse 3 (food production, publicly available). [1]

Sample Product system: bipartite network representation
Direct neighbors of the product node "avocado production" are shown in fig. below (parent and child nodes not shown).

Measlescule structure of the production network
LCA models represented as bipartite networks have a bow-tie structure.

Processes degree (technosphere)

Cavities
- Which representation: bipartite, or monopartite projection ?
  - Monopartite projection is used in [2].
  - Projection of bipartite networks is tricky, requires statistical validation.
- Weighted analysis: tricky.
- Network measures on bipartite networks are specific.
- LCI databases reflect partially actual processes running in industries:
  - Modeling error, uncertainty in parameters' values, mixing flows/processes.
  - One product vs all economy: total demand usually equal to 1 unit of product under study.
- Weighted analysis is hard: units [2]

In-out matrix by category (techno+biosphere)

Descriptive statistics

<table>
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<th>indicator</th>
<th>Agri3 proc. flows</th>
<th>Ecoinvent 2 [2]</th>
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<tr>
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<td>mono (proc./proc.)</td>
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<td>nb. edges</td>
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<td>(k)</td>
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<tr>
<td>median(k)</td>
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<td>7</td>
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<tr>
<td>std(A)</td>
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<td>8.1</td>
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<td>diameter</td>
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</tbody>
</table>

Sparse graph with small diameter.
- 1 large connected component.
- Average degree low but flow have high dispersion.
- Specific bipartite quantities are needed, and Ecoinvent graph.

Networks characteristics change when including biosphere.
- Processes can take dozens of inputs and output a few products only.
- No fat tail.
- When biosphere is included, max degree is much larger.

Bibliography
- Agribalyse 3, ADEME, INRAE.
- Acknowledgments: images from openclipart.org and cliparts by Jean-Christophe Balin.