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Software sensors for bioprocesses

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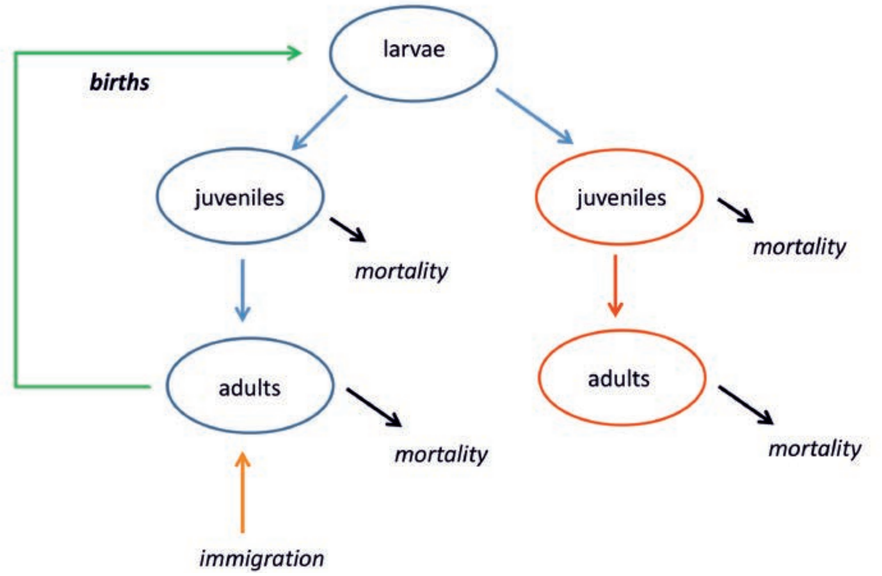
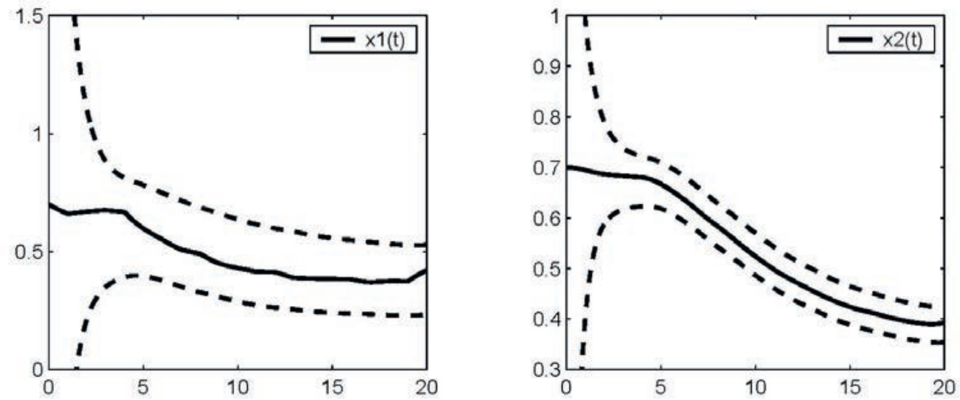


▲ *Figure 1. Simply by observing infertile adult populations (red), all other populations can be reconstructed over time.*
From De Dreuzy J.R. and Rapaport A., 2013. Mieux gérer les ressources naturelles, Les mathématiques de la Terre, Textes et Documents pour la Classe *(TDC). 1062: 20-23.*



▲ *Figure 2. Populations x1 and t x2 (solid lines) were not measured. Dashed lines represent guaranteed boundaries provided by interval observers.*
From Rapaport A. and Gouzé J.L., 2003. Parallelotopic and practical observers for nonlinear uncertain systems. International Journal of Control. *76(3): 237-251. https://doi.org/10.1080/0020717031000067457*

Software sensors for bioprocesses

Sensors available for biological monitoring often do not provide continuous measurement of all variables describing reaction progress (or they are unreliable or too expensive). Through a mathematical model, these unmeasured variables can nevertheless be reconstituted over time as a function of other available measurements using software sensors (e.g. Kalman filters). Specific mathematical conditions are required for building these software sensors, especially the observability property (i.e. the possibility of reconstructing the state of a system from observation data). Not everything is possible of course. Studies on this property allow sensor selection (from among those available) to enable the reconstruction of unmeasured variables (*See Fig. 1 above*).

The sensor choice is not always intuitive for large or complex systems. Some terms of the biological model are at times poorly known or uncertain (e.g. growth rate depending on the climatic conditions). When the statistical data are not sufficiently abundant to support probabilistic hypotheses on uncertain situations, but the poorly known terms are functionally bounded, 'interval observers' can be implemented. Instead of means and variances, guaranteed lower and upper values can be determined for each unmeasured variable over a time course. A pair of software sensors is thus obtained rather than a single one (*see Fig. 2 above*). This guaranteed approach is well adapted to transient bioprocesses (tanks containing microorganisms that transform matter, e.g. fermenters, digesters and water purification bioreactors), where there is a risk of biomass washout when their concentrations are too low, which has to be detected as early as possible. Mathematically, this technique is based on the cooperativity property of dynamical systems, which is not always verified by models but can be applied more conservatively to combined variables.

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