ML-Aided Simulation: A Conceptual Framework for Integrating Simulation Models with Machine Learning

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Integrating M&S with ML: Why, When, How?

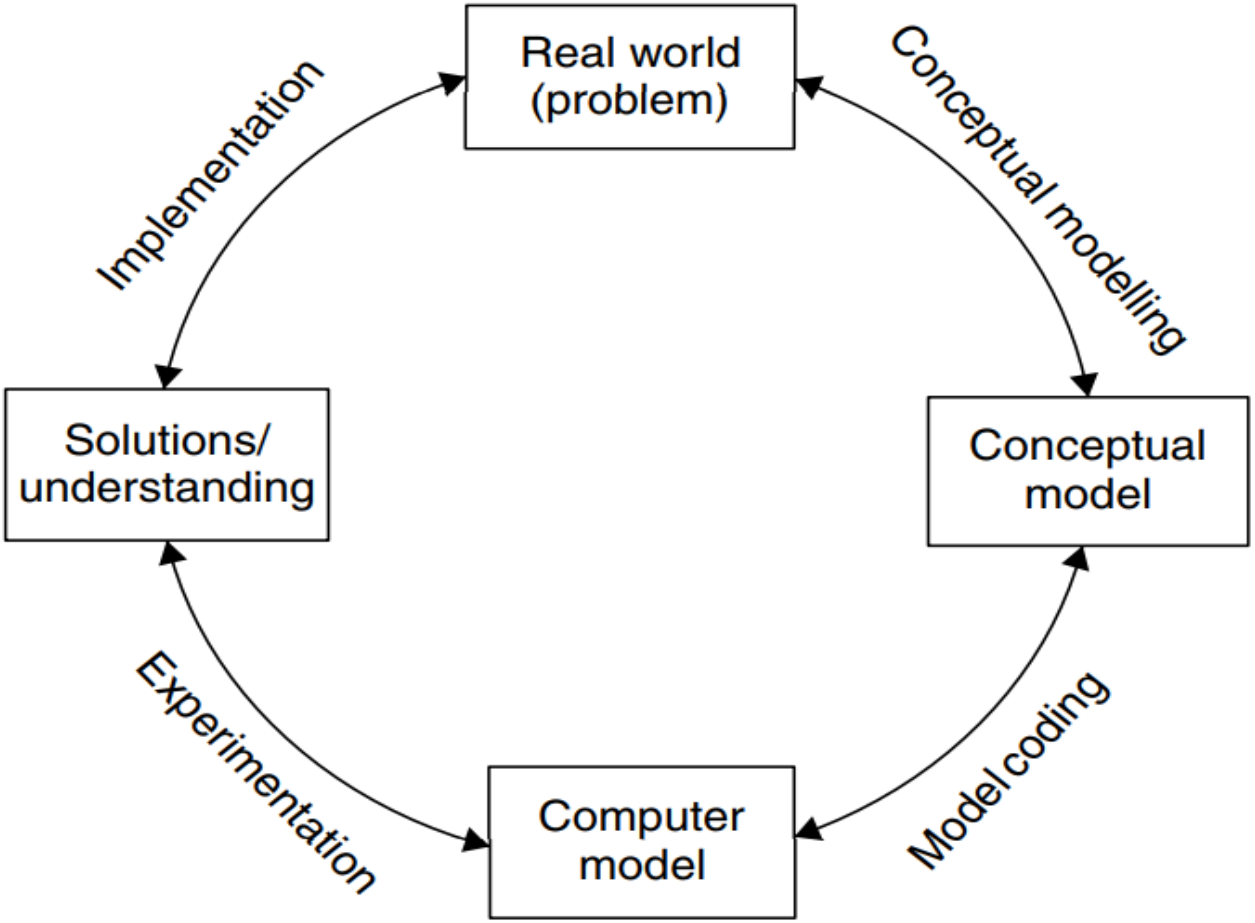
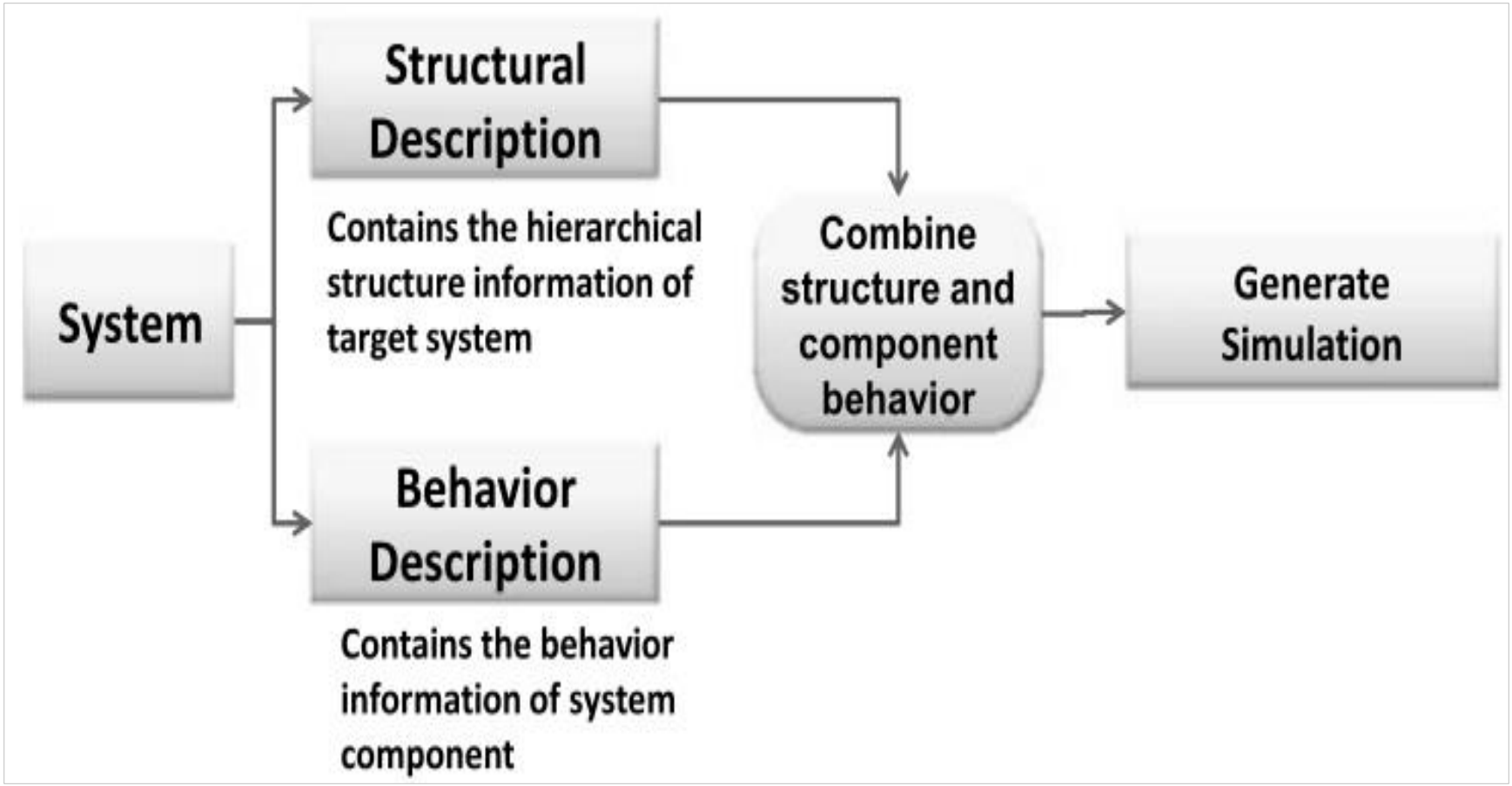


Image Source:
Robinson, S. (2004). *Simulation: The Practice of Model Development and Use*. Chichester: Wiley.

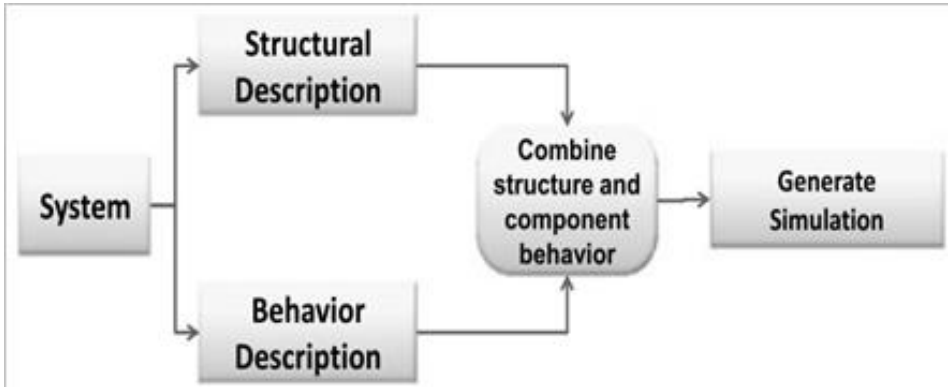
Basic View on Systems & Simulations



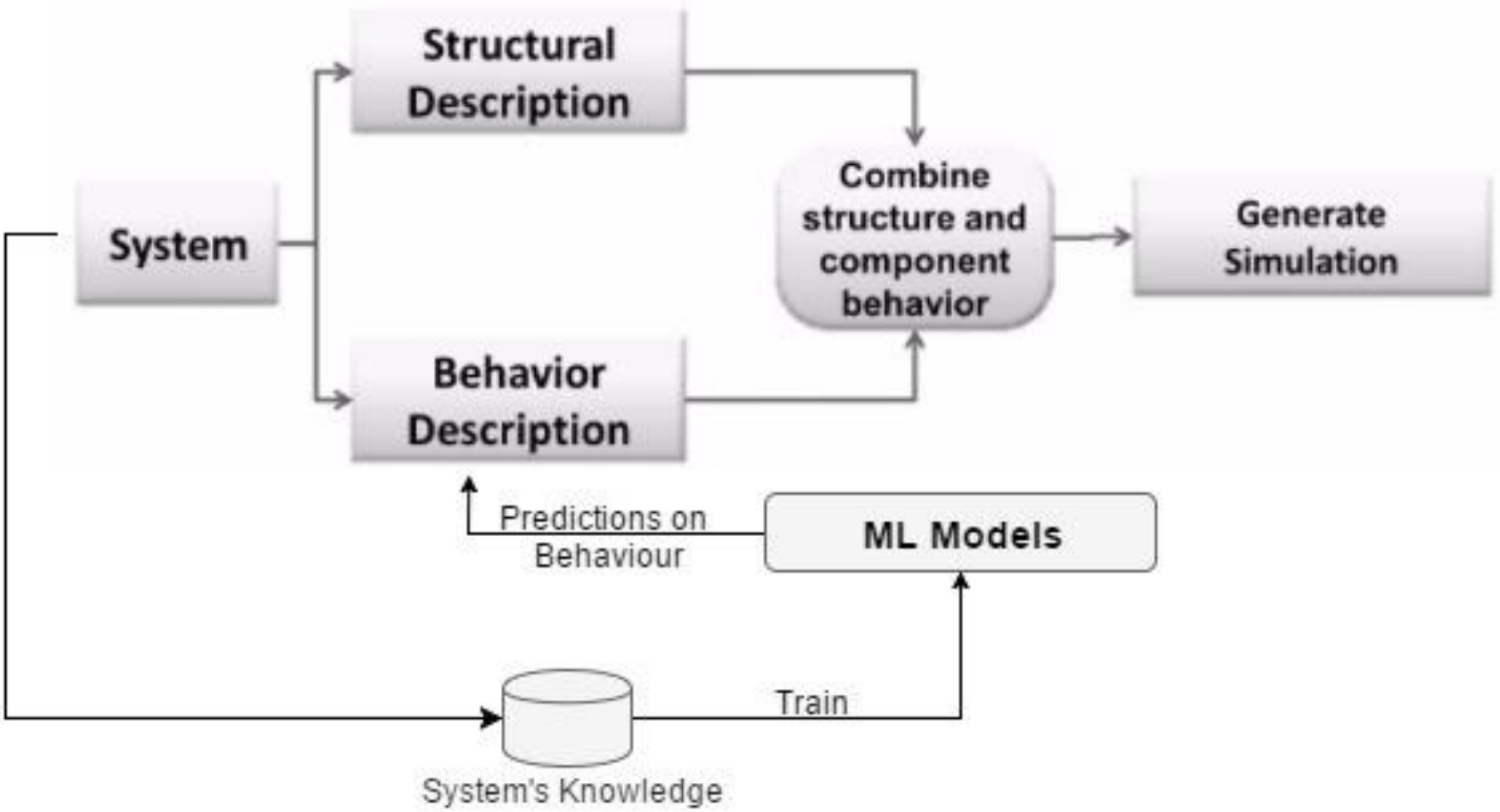
Source: Zeigler, B.P. and Sarjoughian, H.S., 2012. Guide to modeling and simulation of systems of systems. Springer Science & Business Media.

Motivational Questions

- How simulation models can learn about changes in the actual system behaviour with minimal human input?
- Is it possible to integrate simulation models with ML models to enable that learning process to happen in an automated manner? If so, how?
- Can the integration with ML lead to a higher level of confidence in simulations, given by a more measurable accuracy of ML models?



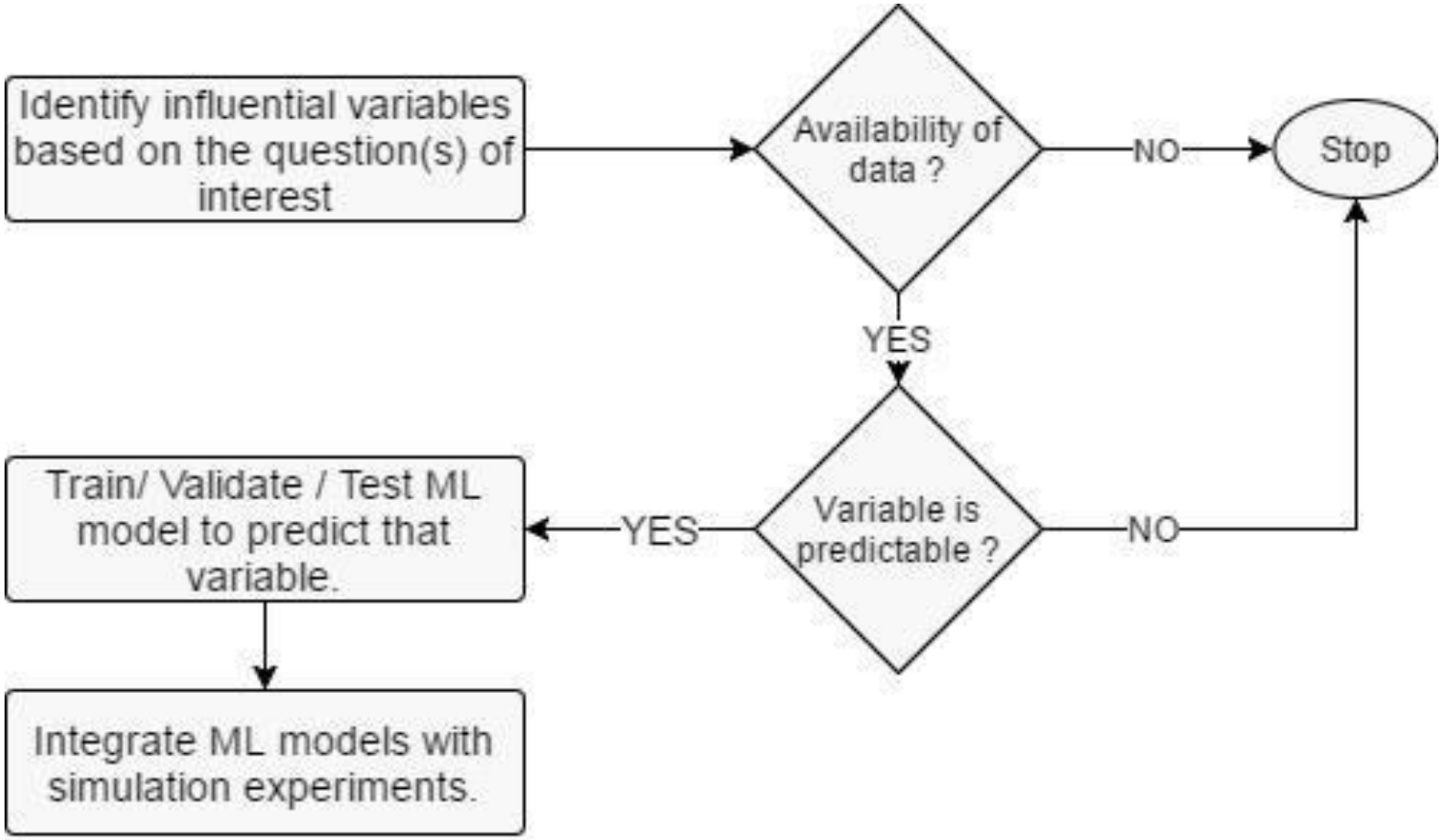
Key Idea 1:
Learning to Predict the System Behaviour



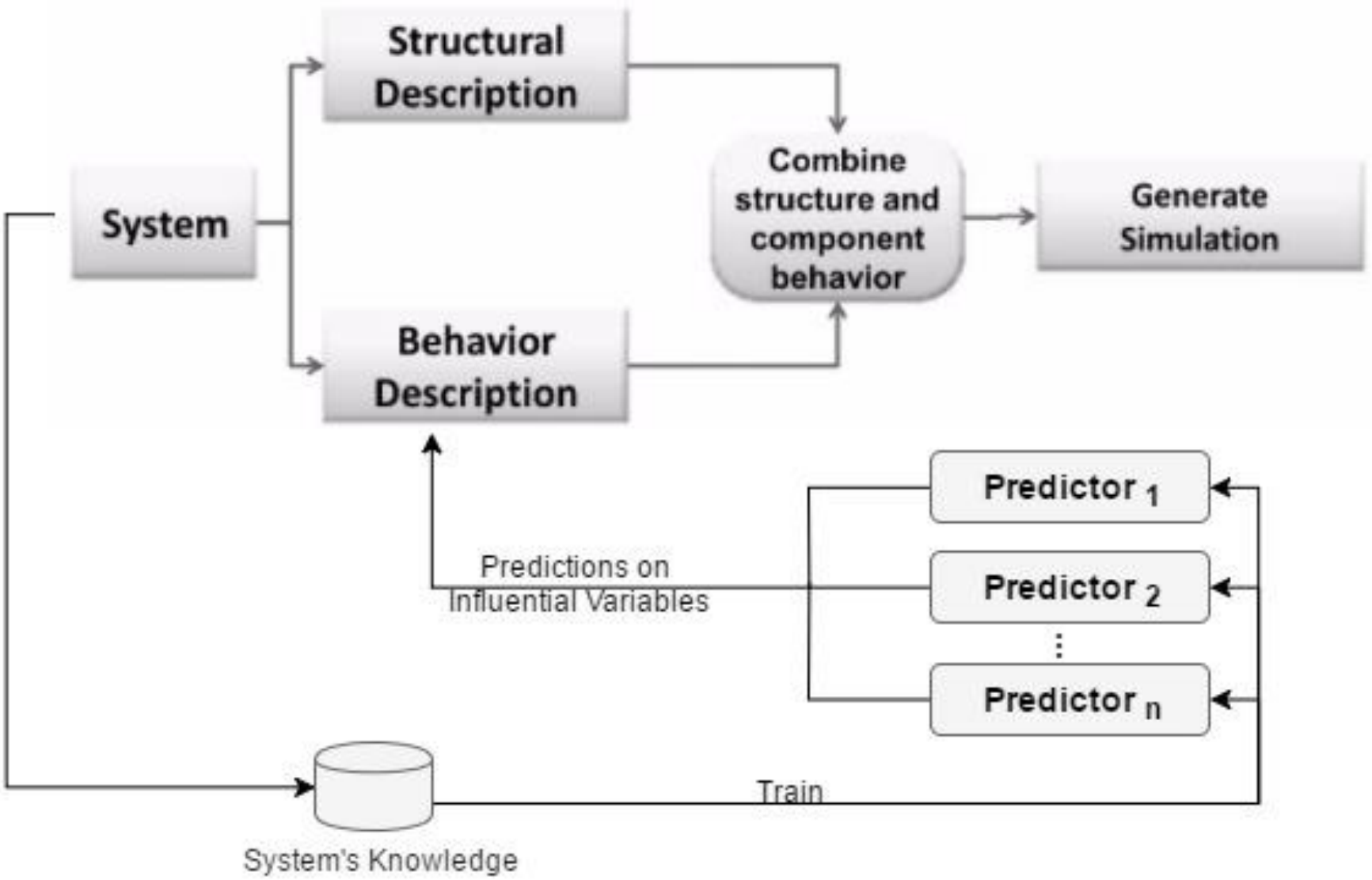
Key Idea 2:
Identify Predictable Influential Variables

- **Influential Variable:** A variable that has a significant influence on the system behaviour with respect to the question(s) of interest, whereas the variation of that variable can lead to a change in policy, strategy, or decision-making.

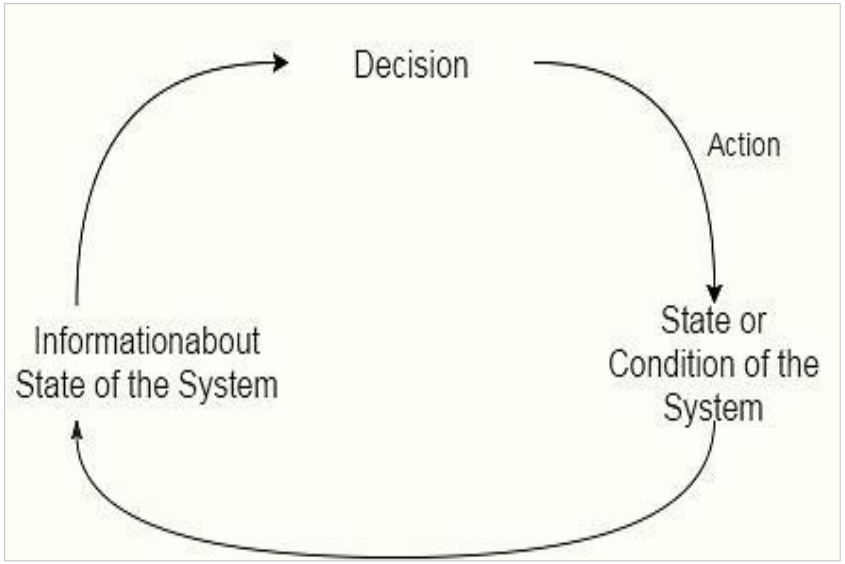
Key Idea 2:
Identify Predictable Influential Variables (cont'd)



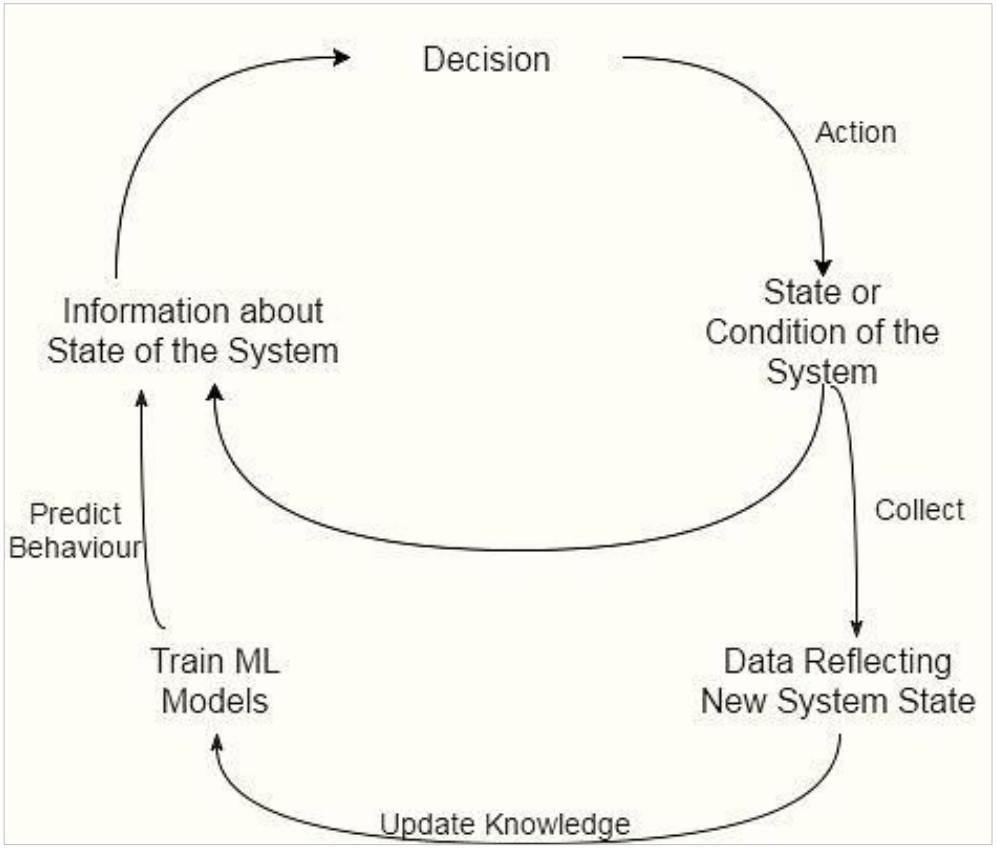
Key Idea 2:
Identify Predictable Influential Variables (cont'd)



Key Idea 3:
Incremental Learning = Adaptive Behaviour



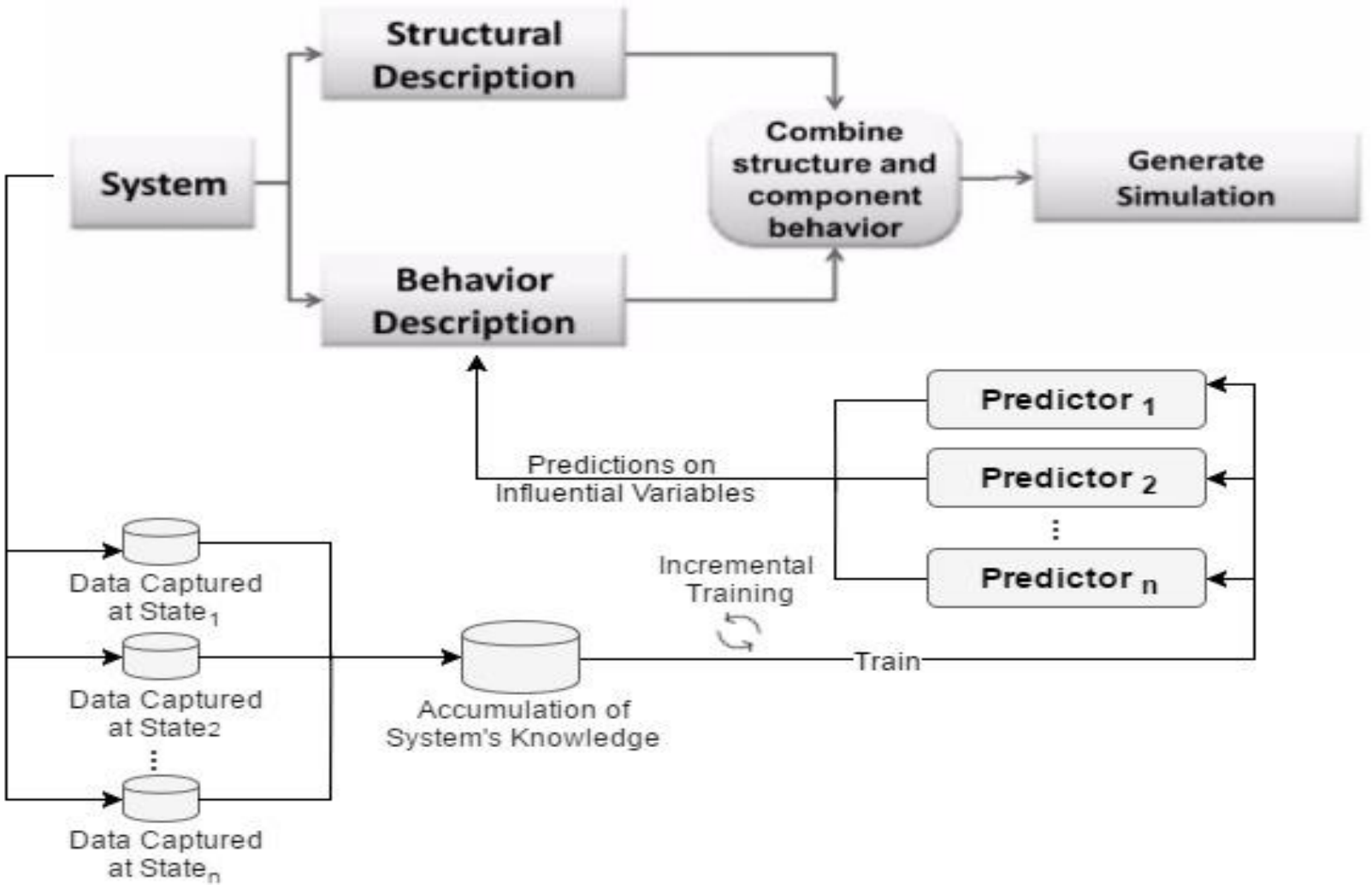
A Basic Feedback Loop [1]



Feedback Loops Aided by ML.

Source: Forrester, J.W., 1968. Principles of Systems, Text and Workbook, Wright-Allen Press-US.

Key Idea 3:
Incremental Learning = Adaptive Behaviour (cont'd)

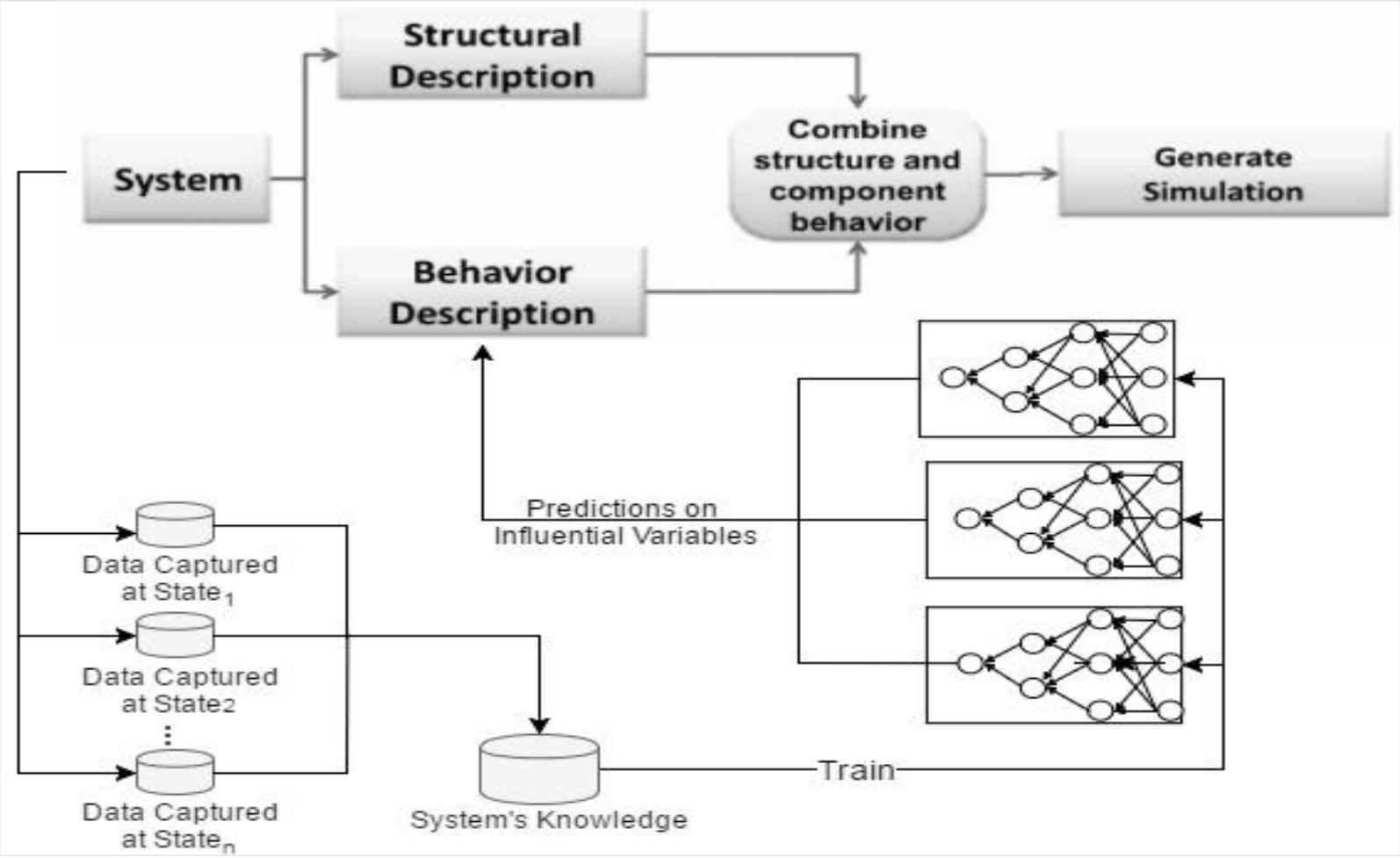


How This Can Be Useful?

- The power of learning from data is that the entire process can be automated with minimal, or without, involvement of human input.
- This can be useful for modeling dynamic systems that exist in rapidly changing environments (*Concept Drift*).
- Realising "self-adaptive" simulation models that can adapt their behaviour based on ML predictions.
- May help reduce the epistemic uncertainty[1] attributed to the subjective interpretation of system knowledge.
- Works effectively in situations where the system behaviour can be largely described and learned by examples.

Source: Oberkampf, W.L., DeLand, S.M., Rutherford, B.M., Diegert, K.V. and Alvin, K.F., 2002. Error and uncertainty in modeling and simulation. Reliability Engineering & System Safety, 75(3), pp.333-357.

Further Directions: More Complex ML for More Complex Systems



Closing Thought

- **Machine Learning:** The subfield of computer science that gives computers the ability to learn without being explicitly programmed (**Arthur Samuel 1959).**

- **ML-Aided Simulations:** Simulation models given the ability to adapt to new knowledge without being explicitly informed by modellers.

Source: Samuel, A.L., 1959. Some Studies in Machine Learning Using the Game of Checkers. IBM Journal of Research and Development, 3(3), pp.210-229.

THANK YOU!

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