Applying the FS^2 model to describe design and development situations: Two outline examples

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This document supplements the article *Feedback Systems in the Design and Development Process* (Wynn and Maier, 2022). We provide two outline examples of applying the Feedback System Function Structure (FS^2) model to frame some design and development process (DDP) situations. The examples demonstrate how to interpret the elements of the model for specific situations, and suggest how doing this can yield insight. Other ways of applying the FS^2 model are suggested by Wynn and Maier (2022).

1 Applying the FS^2 model to describe a process modelling intervention

In this application, the FS^2 model was used to retrospectively frame and reconsider a design process modelling intervention. The objectives were to (1) further clarify the model elements by providing examples, and demonstrate how to interpret them in a specific situation; (2) show how insights into design process modelling arise from analysing it as a feedback system.

1.1 Situation to be analysed

The situation to be analysed is a process modelling intervention undertaken at a UK aerospace manufacturer. During the intervention, the existing engineering design process for a jet engine component was first modelled using the Applied Signposting Model, which is a flowchart-based process modelling approach that emphasises engineering design iteration. The modelled process was then redesigned to integrate some additional activities relating to life-cycle engineering. Monte-Carlo simulation was used to investigate the time and effort implications of the proposed changes, considering how the new activities would be implicated in design iterations. A detailed description of the intervention is available in Kerley et al (2011) and a brief analysis of it from a cybernetic perspective can be found in Wynn et al (2010).

This situation can be perceived as a series of cycles, each involving changes to an emerging model guided by feedback from the process participants and by other observations made by the modeller. All three of the system behaviours addressed by the FS^2 model can be distinguished in this situation:

- *Goal-seeking.* The overall intention of the process modelling was to close the gap between the current process and an initially ill-defined desired process (in which the additional lifecycle engineering activities were integrated, ensuring the additional time and effort to complete a component would remain feasible). A multitude of subgoals can be identified as discussed further in the next subsection.
- *Learning.* During the modelling process, a series of iterations was undertaken in which the modeller discussed the as-is process with its participants to gain understanding, attempted to represent that understanding in the evolving process model, and then showed that emerging model to the participants to gain feedback. On each iteration the modellers developed their knowledge of the current state of the process. Later, they developed knowledge about the

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impact of proposed changes to it. Other forms of learning also occurred as discussed in the next subsection.
- *Emergence.* The process model evolved during the modelling process in a way that could not have been anticipated, as did the modeller's and the process participants' appreciations of the process. The modelling work ultimately led to a proposed design for a new process, that was not known before beginning.

1.2 Describing the situation using the FS^2 model

When applying the FS^2 model, most situations could be perceived in different ways. Here, we chose to frame the situation as a feedback system from the point of view of the modelling and process development activity, i.e. focusing on how the modeller interacted with the process model they were developing and with the process participants. To achieve this framing, each element of the FS^2 model depicted in Figure 10 of Wynn and Maier (2022) was considered in turn and interpreted for the context at hand. This involved iteration and cross-checking of the elements against their descriptions in the aforementioned article.

Ultimately, the following description of the situation as a feedback system was developed:

1. *System boundary.* The modeller and their understanding of the process are inside the boundary. The design process participants and existing process documentation are outside the boundary. The process model being developed through iterations, as represented in a process modelling tool, is also outside the boundary.
2. *Output flow (action on environment).* The modeller makes changes to their emerging process model as represented in the process modelling tool; verbally communicates their understanding to the process participants; and asks them questions about the process.
3. *Input flow (observations of environment).* The modeller reviews documentation of the current process. They collect feedback from process participants after showing them the emerging model, after explaining their understanding of the process, and after posing questions about that process. They also observe the results of process simulations using the modelling tool.
4. *Goals.* The FS^2 model allows for multiple goals, which may be in conflict. In this case, the goals include:
   - To develop a process model that adequately represents the actual design process;
   - To ensure the model represents the actual design process at an appropriate level of detail to localise the desired lifecycle engineering tasks and their connections to other tasks;
   - To ensure the model represents the iterative structure of the design process closely enough that participants find it believable;
   - To ensure the model is graphically simple enough to be quickly understood by the process participants.
   - ...

   This is not an exhaustive list. Additional goals include, for example: To ensure the model is simple enough to simulate in reasonable time; To ensure the nomenclature within the model is consistent; and so on.
5. *Perceived situation (current state).* This represents the modeller's evolving understanding of the design process, and their appreciation of how their emerging process model represents that process.
6. *Decision heuristics.* These represent the modeller's rules of thumb that are applied to reduce deviations from their modelling goals. Examples include:
   - If their emerging model is seen to be (or expected to become) too densely connected to remain readable, they should remove some information flows that do not constrain task sequences.
   - If they determine the model is lacking detail in a certain area, they should approach a certain person for additional information.
   - If simulation of the modelled process is observed to not terminate, this indicates a problem with configuration of the iteration loops. The modeller may first disable all iteration loops, then add them one-at-a-time to locate the problem.
   - ...
7. *Detect function.* The modeller's understanding of the actual process, and of the emerging process model, are compared to identify discrepancies with respect to the goals. For example, it may be determined that the model is not detailed enough in a particular area, or that certain task patterns that are known to exist are not accurately represented in the emerging model. To give another example, it may be detected that an attempted process simulation did not terminate.
8. *Situation model (cause and effect).* To recap, situation models allow feedback system participants to (1) predict how the environment might evolve; and (2) predict how it might respond to actions, both with respect to goals and based on an appreciation of dependencies.

In this case, some of the important actions concern changes being made to the emerging process model as explained above. Therefore the situation model comprises aspects of memory that allow the modeller to think through the effects of proposed changes (to some degree) without needing to first put them into effect. To give two examples: it includes an understanding that the readability of a process flowchart model is dependent on the density of information flows (among many other factors); and an understanding of how certain configuration options in the simulation tool affect the simulation output.

9. *Predict function.* The modeller thinks through the effects of actions and how they might cause future deviations from goals, without putting those actions into effect. For example, the modeller may foresee that asking participants to name all the potential inputs to every task, and incorporating them as information flows in the model, will eventually result in the process model having too many crossing arrows to be easily readable, and being difficult to configure for simulation. To give another example, they also attempt think through proposed simulation logic and predict whether it will work as intended before taking action to implement that logic in the modelling tool.
10. *Decide function.* The modeller applies decision heuristics and considers the perceived situation when deciding how to reduce detected and predicted deviations from goals. This includes deciding how to manage tradeoffs between goals, for example, the modeller will take into account the conflict between creating a model that depicts all possible information flows and one that is easy to visualise.
11. *Implement function.* The modeller makes changes to their model as represented in the process modelling tool. They initiate conversations with process participants about the emerging model, request certain information required to improve the model, and so on.
12. *Learn I function (affecting situation models).* The modeller's understanding of dependencies in their environment, and how those might affect the environment's evolution, develops through iterations as they better appreciate the environment and its response to previous actions and changes. For example, after running simulations, they develop a better understanding of how certain tasks and iteration loops affect the overall duration of the process.
13. *Learn II function (affecting goals).* The goals evolve during the modelling process as the modeller gains a better understanding of the situation. For example, the modeller may refine their goals for the scope and level of detail of the model as they better understand what is required to localise the new life-cycle engineering activities.
14. *Abstract function (affecting decision heuristics).* The modeller extracts decision heuristics (rules of thumb that guide their decisions with respect to the modelling goals) from their situation models. As the goals and the situation models evolve, this also leads to changes in the decision heuristics. For instance, as the modeller gains a deeper understanding of how process participants respond to certain changes to the emerging model, or a deeper understanding of how the simulation can be configured, they adjust their decision-making heuristics with the intention that future actions are more effective.
15. *Perceive function (affecting perceived situation).* The modeller observes many aspects of their environment, including participants' explanations of different aspects of their processes, documentation, and so on. They filter these observations through the lens of their own understanding of the modelling goals, of their emerging model and of the process. For example, they may decide that certain information is not relevant to their objective of modelling tasks and information flows, is too detailed to warrant consideration in the model, etc. To give another example, early in the modelling process they may not be able to extract insight from certain explanations provided by process participants, since they do not yet understand the design process in enough detail to put those explanations into context.

The above text provides an outline description of the situation. It could alternatively be described at a more granular level, for example focusing on specific goals or stages of the modelling process.

1.3 Some insights gained

Several insights were developed from describing the situation using the FS^2 model.

Firstly, analysing design process modelling and improvement as a process of convergence on goals led to an appreciation that there is a multitude of such goals, and that some are in conflict. Considering the goals helped to unpack some desirable attributes of process models and process modelling, that had previously been considered only implicitly. A more in-depth analysis of the goals and their interactions could, perhaps, be developed into modelling guidelines to help novice modellers address them.

Secondly, the FS^2 model helped to appreciate process modelling and simulation as a situation in which the modeller's understanding of the process being modelled is distinct from the content of the emerging process model. Appreciating the importance of learning in process model suggests that frequent and rapid feedback on an evolving process model is likely to be desirable. Also relating to learning, it became clear that the goals for process modelling are (like design goals) initially ill-defined and evolve over time as a modelling project proceeds.

Thirdly, describing the situation using the FS^2 model helped to reveal how the modeller's understanding of the process, filtered through the lens of the modelling approach they are using, impacts the questions they ask and the information they seek, and hence, influences the form of the developed model. One recommendation is therefore that a process modeller should reflect upon how the approach they choose to apply affects their perceptions of the process and may lead them to overlook issues that might be important. At the same time, the emerging model affects the perceptions of the process participants who the modeller interacts with during the modelling process; feedback provided by those process participants on each discussion is influenced by the form of the emerging model they are shown. To give an example, when faced with a process flowchart model, feedback may revolve around the depicted tasks and information flows, and related issues such as scope and granularity, rather than the mechanisms for controlling iterations.

The above text provides only an outline of the kinds of insight that could be gained. While the described insights might not change an experienced modeller's ideas of good modelling practice, the authors found the FS^2 model helpful to collect and express them. Furthermore, analysis of the process modelling intervention through the lens of the FS^2 model helped to appreciate process modelling as a process in itself, that has some similarities to the design process. In particular, process modelling requires working with initially ill-defined goals; involves the development and evolution of those goals, influencing and influenced by the emerging process model; and requires handling conflicts between goals. Perhaps insights into these activities from design research could be interpreted to support process modelling more explicitly.

2 Reflexive application of the FS^2 model to describe its own design and development process

Adopting Reich's Principle of Reflexive Practice (Reich, 2017) we applied the FS^2 model to retrospectively analyse our own design and development process—as had been undertaken to develop the model itself. The objectives were: (1) to test the model's applicability; (2) to identify opportunities to refine its description; and (3) to provide another example to illustrate the model elements and their interpretation.

2.1 Situation to be analysed

The situation to be analysed is the activity that was undertaken by the authors to develop a conceptual model of feedback systems in the design and development process (i.e. the FS^2 model). All three of the system behaviours addressed by the FS^2 model can be distinguished in this situation:

- *Goal-seeking.* The authors progressively developed the FS^2 model to close the gap between (a) the characteristics of the emerging model, and (b) what the authors believed to be the characteristics of a "good" conceptual model. Further discussion of the goals is provided in the next subsection.
- *Learning.* As they worked on the model, the authors developed progressively deeper appreciation of the literature and of the concepts described within it. They also gained deeper insight into how these concepts could be applied to a range of design and development situations, and into how the emerging FS^2 model could be interpreted and applied to generate useful insight. Further discussion of learning during the FS^2 model development is provided in the next subsection.
- *Emergence.* The form of the FS^2 model evolved in a way the authors had not (and could not have) predicted. This occurred as they came to appreciate the issues in greater depth, following an emergent process as they studied research literature and considered issues that fell under their focus of attention.

This was a complex situation because of the broad range, high level of abstraction and richness of ideas in the literature relating to feedback systems in the DDP, allowing many possibilities for interpretation. The emerging FS^2 model was itself also subject to interpretation due to its deliberately abstract nature. Some of the challenges during the model development included achieving enough precision and consistency in the model descriptions, while encompassing a range of quite abstract concepts in a meaningful way. The complexity was handled through a highly iterative approach, involving a series of changes to the model's description which was repeatedly reevaluated in context of concepts from the literature. The model, the researchers' appreciation of literature, and the objectives for the model all coevolved through a long series of iterations until convergence was achieved. As explained next, this situation can be perceived as a feedback system.

2.2 Describing the situation using the FS^2 model

When applying the FS^2 model to analyse the above situation, it could be perceived in different ways. Here, the situation is framed as a feedback system by focusing on how the researchers (within the system boundary) interacted with the description of the model they were developing and how they considered relevant literature (both in the environment). Interactions between the researchers are not considered in this example. To achieve the framing, each element of the FS^2 model depicted in Figure 10 of Wynn and Maier (2022) was considered in turn and its meaning was identified for the context at hand. As with the other example discussed in this document, this was an iterative process and required cross-checking the text against the descriptions of each model element provided in the article.

The following outline description of the situation as a feedback system was developed:

1. *System boundary.* The researchers and their understanding of the emerging model were inside the boundary. The body of literature and all potential test cases, and the realisations (both written and depicted) of the model, were outside the system boundary.
2. *Output flow (actions).* The researchers made a long series of adjustments to the text and to the diagrams that described the emerging FS^2 model, i.e. to the working draft of Wynn and Maier (2022).
3. *Input flow (observations).* The researchers considered the description of their emerging model (seeing the implications of changes, that were not immediately apparent when making those changes). They also read literature and later, considered reviewer feedback on the model description.
4. *Situation model (cause and effect).* This represents the researchers appreciation of the connections among concepts in the emerging model as well as how they relate to concepts in literature. This appreciation allowed the researchers to mentally simulate the effect of potential changes to the emerging model, considering whether those changes would improve internal consistency and whether they would improve consistency with concepts in the literature.
5. *Decision heuristics.* This represents the researchers' rules of thumb regarding how to modify the descriptions of the model to reduce detected/predicted deviations from their goals for the model. To illustrate, some examples include:
   - If the description of the model in the draft article is thought to be too imprecise, ensure diagrams use a consistent notation; identify key terms and check they are consistently used throughout the explanatory text; or add examples from the application domain.
   - If the text of the draft article is too long, try to reduce the longer subsections first, to retain balance.
   - ...
6. *Goals.* The researchers overarching objective was to develop a model that allows the appreciation of DDP situations in terms of feedback, yielding insights that should be useful for practice and/or for further research. This involved several subgoals, including:
   - The model should intended to encompass relevant concepts revealed by literature review.
   - The model should be applicable to an array of design and development process situations.
   - The depiction of the model should be visually comprehensible, and its description should be suitable for journal publication.
   - ...

   The goals evolved during the model's development process; this is not a comprehensive list.
7. *Detect function.* The goals are numerous and evolving, which is reflected in the deviations from goals being detected. To illustrate, some examples include:
   - Determine that a section of the draft article is too long or too short
   - Determine that certain terminology is used in inconsistent ways
   - Determine that a concept from literature is not accurately encompassed in the model.
   - ...
8. *Predict function.* Drawing on their situation model the researchers attempted to think through the consequences of various changes to the model description and diagram, before implementing them, i.e. to predict whether certain changes would ultimately lead to improvements.

9. *Decide function.* On each iteration, the researchers decided how they would adjust the descriptions and/or depictions of the model, considering detected and predicted deviations from goals as well as their appreciation of the model and literature, and their decision heuristics.
10. *Implement function.* The researchers made changes to the text describing the model (by operating the word processor) and/or the diagrams depicting it (by operating the diagramming software).
11. *Abstract function (decision heuristics).* The researchers modified their decision heuristics as their understanding of concepts in the literature and their model, and the relationships among them (their situation model) improved through learning that took place on each iteration.
12. *Learn I function (situation models).* Through a series of iterations, the researchers developed deeper insight into the concepts in literature, their relationships, and also about the concepts and relationships in the described model. For example they recognised additional connections between concepts, and took on board additional ideas when reading or rereading a paper. This learning changed the pattern of their future iterations.
13. *Learn II function (goals).* As iterations proceeded, the goals for future iterations were also further developed, including further decomposition into subgoals concerning specific elements of the model and its description. This was driven by the model increasing in conceptual richness allowing the drivers of internal consistency to be more precisely pinned down, and by consideration of additional applications (such as this example) expanding the set of test cases for the emerging model.
14. *Perceive function.* The literature relevant to the FS^2 model is vast, and the publications that were considered contain a very rich set of related concepts, described in different terms by their respective authors. The researchers extracted insight from each paper that was filtered through their own evolving appreciation of the topic. Papers and their content were also filtered through the lens of the emerging model which influenced what was deemed relevant. Also, when considering the emerging description and depiction of the model, the issues that were perceived and focused on were influenced by what was on the mind of the researcher at each point in time.

2.3 Some insights gained

Consideration of the FS^2 model's design and development process through the lens of the FS^2 model revealed insights about that process and also led to improvements to the model's concepts and to its description.

In terms of insights into the model development process, reflexive application of the FS^2 model helped the researchers to recognise the value of having a range of test cases against which to test it. In particular it led the researchers to consider how the model applies to conceptually rich and ambiguous situations such as its own development, as well as to more well-defined systems of activity such as the CAE design example discussed in Wynn and Maier (2022). Refinements of the article to encompass these insights included the explicit explanation that concepts exist only within a system while actions on the environment are objectively observable emissions such as a stream of words, modifications to a text or a diagram. Another refinement developed from the reflexive application was the realisation that the model description did not initially establish the distinction between aspects of the environment that have bidirectional influence with the system (in this example, the FS^2 model description being developed through cycles of iteration and feedback) and aspects that are only inputs to the system (in this example, literature that is relevant to the FS^2 model development).

3 Summary

Overall, it is intended that this document will help to clarify the FS^2 model by providing examples, demonstrating how it can be interpreted, and showing how it can yield insight.

References

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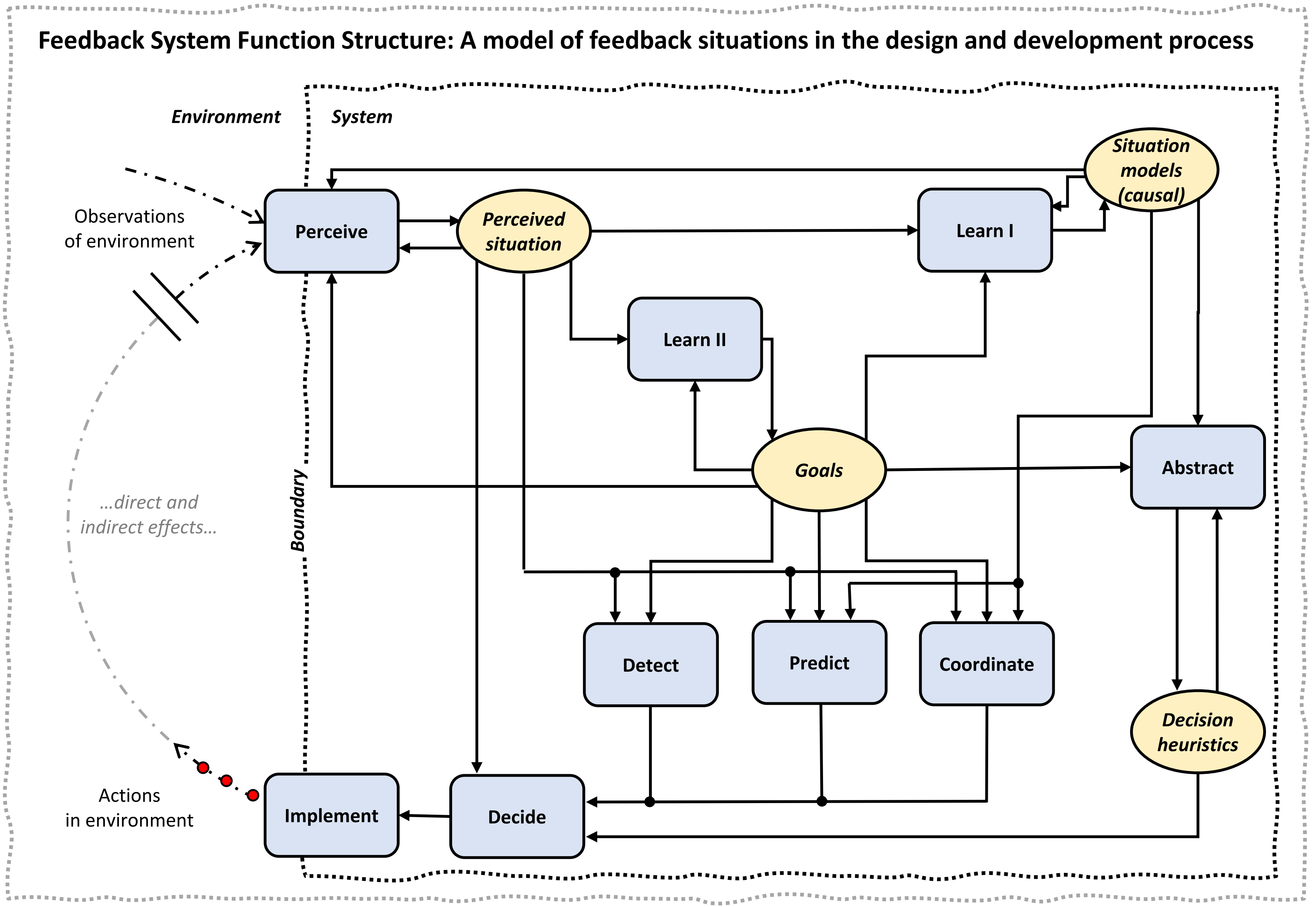
Feedback System Function Structure: A model of feedback situations in the design and development process
Environment
System
Observations
of environment
Perceive
Perceived situation
Learn I
Situation models (causal)
Learn II
Goals
Abstract
Boundary
...direct and
indirect effects...
Detect
Predict
Coordinate
Decision heuristics
Actions
in environment
Implement
Decide

The table shown below explains how the pattern of ticks in **Table 3** of the article was generated.

Each publication was systematically examined to answer 'Yes' or 'No' for each of the questions in the table.

A tick was placed in Table 3 for a function if the answer was 'Yes' for any one of the respective questions.

Function	***Does the publication emphasise…***
Detect	…that the system involves identification of deviations from a desired state?
Predict	…that the system anticipates or predicts future deviations from a desired state?
Decide	…that the system involves decision-making specifically to reduce deviations?
	…that the system considers tradeoffs among goals/strategies when decision-making?
Implement	…that actions to reduce deviations are distinct from decision making?
Learn I (situation)	…that the system's understanding of cause and effect evolves as a result of system operation?
	…that the system's understanding of cause and effect evolves as a result of conscious reflection?
Learn II (goals)	…that goals evolve due to the system's operation?
	…that goals are modified as a result of conscious reflection?
Abstract (heuristics)	…that the system formulates rules or heuristics to inform decisions?
	…that the system formulates strategies for approaching goals?
	…that the system identifies a subset of the known factors to be considered when making decisions?
Perceive	….that perceived state/goals/situation models influence how a situation is perceived?
Coordinate	…that a system's information processing takes into account the need for coordination?