SYSTEMS OF THINGS THAT FLOW

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ABSTRACT

Diagrammatical descriptions are used extensively in understanding systems. Typically, systems are expressed in terms of heterogeneous symbols that represent basic characteristics of the system, including elements, connections, flows, communication, etc. This paper introduces a new model to describe flow-based systems. It models "things that flow," such as information, materials, actions, and money. They are distinguished by flowing in five states: received, processed, created, released, and communicated. The new model is applied to typical systems to contrast them with classical descriptions.

Keywords: flow model, system modeling, conceptual modeling

INTRODUCTION

Systems approach is a valuable methodology for understanding organizations and solving problems. Diagrams are widely used tools for describing systems. Prior to quantifying processes of a complex systems problem, the configuration of the system components and their interconnections must be visualized.

The "flows" inside the system are important factors in the intertwining of its connected components. This paper concentrates on a specific type of system: a system of "things that flow." "Things that flow" include information, materials (e.g., in manufacturing), money, etc. The notion of flow is a widely used concept in many fields of study. In economics, the goods circular flow model is well known; in management science there is the supply chain flow. In computer science, the classical model of flow is the 1949 Shannon-Weaver communication model, representing electrical signal transfer from sender to receiver. It reflects the concept of "flow" in terms of three stages: information being transmitted, information in the channel, and information being received. Flow of information means the movement from one information sphere (the sender) to another information sphere.

Typically, systems are described in terms of heterogeneous symbols that represent basic characteristics of the system, including elements, flows, communication, etc. These descriptions mix types of flows. The resultant diagram is a rough sketch of related ideas, not appropriate to be called a system because the mere word "system" gives the impression of reasonably clear components and relationships.

Alternatively, we use a flow model (FM) that separates different types of flow with the possibility that one flow "triggers" another flow. The flow indicates movement of a single type of thing inside and between spheres. The sphere is the environment of the flow and includes five stages with possible sub-spheres (e.g., storage). The stages may be named differently according to the things that flow. For example, in an information sphere, a stage may be called *communication*, while in raw material flow the same stage is called *transportation*.

The main purpose of this paper is to raise interest in FM in the area of systems sciences. We will first review FM as described by Al-Fedaghi (2008a, 2008b, 2008c), with some new illustrations of its characteristics. Formalization of some of FM features will also be described. Next a classical description of a reservoir with feedback will be given to illustrate the advantages of FM modeling.

RELATED WORKS

Graphical representation is commonly utilized to communicate a system's functional and data flow characteristics and requirements. The Function Flow Block Diagram (Blanchard and Fabrycky 1990), Data Flow Diagrams (DeMarco 1979), Use Case, Sequence Diagram, and Behavior Diagram are examples of such representation. General informal graphical diagrams are also used in systems sciences. It is this last type of diagram that is targeted in this paper. One objective of developing a new flow model is that it be used to enhance these types of graphical representations of systems.

The notion of flow has appeared in numerous works in systems science. However, it seems that it has not been used as the fundamental characteristic of system the way FM has. The clearest emphasis on flow is expressed by Simon and Clair (1998) as follows:

> [F]or an electric-power generation and distribution system, the systems engineer will show in diagrammatic form how the energy flows as it is converted from the basic fuels to steam in boilers, then into steam turbines; or from waterfalls to water turbines to electric generators; then through transformers, through switching systems, transmission lines, and out to the various users where, again, it is altered in form many times. This would be an energy flow chart, and it would serve as a backbone around which additional systems considerations will be studied. To accompany this an information flow chart would be created because none of the switching systems, motors, generators, and people, acting over what might be a very great geographical span, would know what to do unless they are directed to do so by a control network that moves the information about, stores that information where required, processes it, interprets it, etc.

FLOW MODEL

The flow model (FM) was first introduced by Al-Fedaghi (2006) and has been used since then in several applications, including engineering requirement analysis (Al-Fedaghi, 2008a, b, and c).

Systems of Things that Flow

In FM, the flow of "things" indicates movement inside and between spheres. The sphere is the environment of the flow and includes five stages that may be sub-spheres with their own five-stages schema. The stages may be named differently. For example, in an information sphere, a stage may be called *communication*, while in raw material flow the same stage is called *transportation*. The information *creation* stage may be called *manufacturing* in the materials flow. We will move between these terms as the spheres change.

In reviewing FM, we will assume that the "thing that flows" is information. An information sphere denotes the information environment (e.g., company, department, or person). The lifecycle of information is a sequence of states as it moves among stages of its lifecycle as follows:

1. Information is received (i.e., passengers arriving at an airport).

2. Information is processed (i.e., subjected to some type of process, e.g., compressed).

3. Information is disclosed/released (i.e., it is designated as released information, ready to move outside the current sphere, like passengers ready to depart from airports).

4. Information is transferred to another sphere (e.g., from a customer's sphere to a retailer's sphere).

5. Information is created (i.e., generated as a new piece of information using data mining).

6. Information is used (i.e., it is utilized in some action, analogous to police rushing to a criminal's hideout after receiving an informant's tip). Using information indicates exiting the information flow for another type of flow such as action. We call this point a gateway in the flow.

7. Information is stored. Thus, it remains in a stable state without change until it is brought back to the stream of flow.

8. Information is destroyed.

The first five states of information form the main stages of the stream of flow, as illustrated in Figure 1.

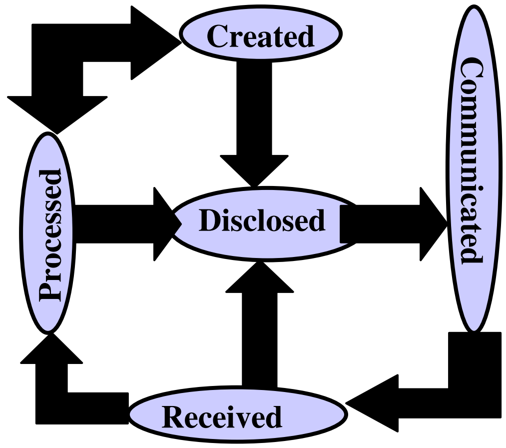

Figure 1. The basic information flow model.

When information is stored, it is in a sub-state because it occurs at different stages: information being created (stored created information), processed (stored processed information), and received (stored received/row information). The five-stage scheme can be applied to humans and organizations. It is reusable because a copy of it is assigned to each agent.

The five information states are the only possible "existence" patterns in the stream of information. To follow the information as it moves along different paths, we can start at any point in the stream. Suppose that information enters the processing stage, where it is subjected to some process. The following are ultimate possibilities:

1. It is stored.

2. It is destroyed.

3. It is disclosed and transferred to another sphere.

4. It is processed in such a way that it generates implied information (e.g., *a is the father of b and b is the father of c* generates the information that *a is the grandfather of c*).

5. It is processed in such a way that it generates new information (e.g., comparing certain statistics generates the information that *Smith is a risk*).

6. It is *used* to generate some action (e.g., upon decoding or processing the information, the FBI sends its agents to arrest the spy who wrote the encoded message). In the uses sub-stage, information is not a patient. The patient is a term that refers to the thing that receives the action.

The storage and uses/actions (called gateways) sub-stages can be found in any of the five stages. However, in the release/disclosure and communication stages, information is not usually subject to these sub-stages, so we apply these sub-stages only to the receiving, processing, and creation stages without loss of generality. Figure 2 shows the interiors of these stages.

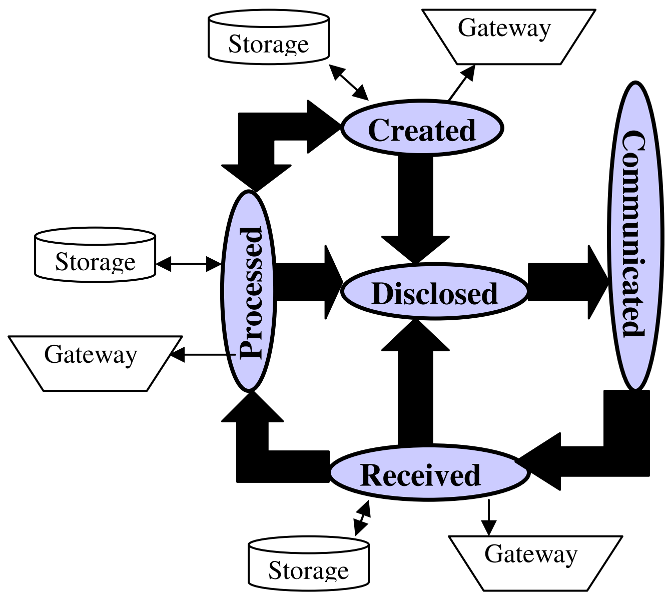

Figure 2. FM sub-stages.

The "storage" in each stage represents information in a static state. Thus, as information is received, it may be stored in its received condition for a later time when it is activated by being returned to the flow stream. Implicit in Figure 2 is the fact that information may be destroyed and/or duplicated through copying.

Figure 2 is a detailed version of Figure 1, showing how the receiving stage leads to the processing stage, which in turn leads to the creation stage. The creation stage may lead back to the processing stage. These three stages may lead directly to the disclosure/release stage, then the transmission stage, which in turn leads to the receiving stage of another sphere.

To illustrate the "gateway" sub-stage, imagine that a person in Barcelona (sender) uses the Internet to ask a person (recipient) in New York whether it is raining in New York. Figure 3 illustrates the information flow. First, the query flows through narrow arrows to the receiving stage of the New Yorker. It triggers (dotted arrow = gateway) the New Yorker to some type of action (e.g., opening the widow to check whether it is raining). Triggering indicates a change in the "thing that flows" from information to actions. Actions also can be received, processed, created, released, and transported. The action of the New Yorker triggers (dotted arrow = gateway) the creation of a response (information) that flows back (bold arrows) to Barcelona. The receiving and disclosure stages in the systems have been duplicated in order to simplify the figure. We ignore here the fact that mental information is ontologically different from digital information.

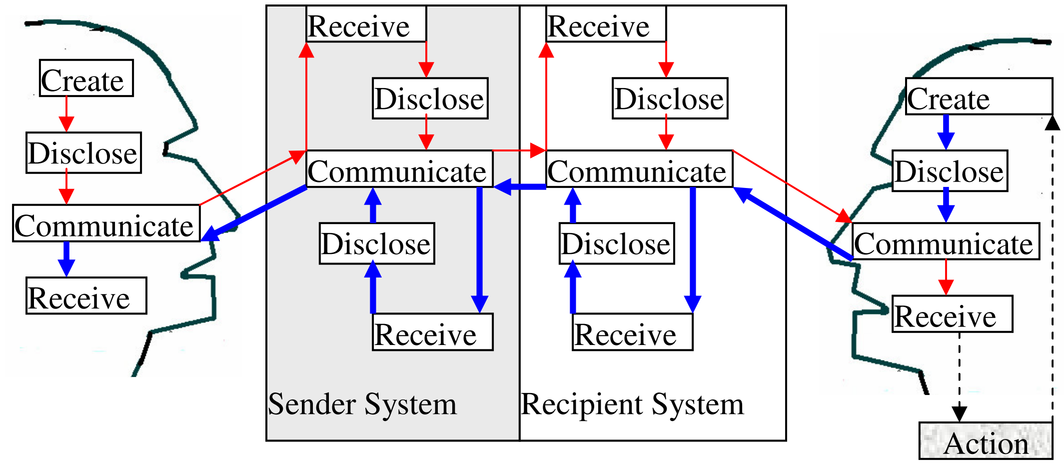

Figure 3. Flow of information through gateway that triggers an action.

FORMALIZATION OF FM

According to De Rosnay (1979),

> The most widely used definition of a system is that it is "a set of interacting elements that form an integrated whole." A city, a cell, and a body, then, are systems. And so are an automobile, a computer, and a washing machine! Such a definition can be too general. Yet no definition of the word system can be entirely satisfying; it is the conception of system that is fertile-if one measures its extent and its limits."

De Rosnay (1979) goes further to provide the most complete definition:

> A system is a set of elements in dynamic interaction, organized for a goal. There is nothing mysterious about the "goal" of the cell. It suggests no scheme; it declares itself a posteriori: to maintain its structure and replicate itself. The same applies to the ecosystem. Its purpose is to maintain its equilibrium and permit the development of life.

In FM a system is the five stages schema and may include sub-stages as described previously. Next we concentrate on developing such a definition of a system.

What is a System?

FM is a model of *things that flow*. To use a neutral term, we will use the term *flowthing* to denote a thing that flows, hence, is received, processed, created, released, and communicated. In FM, a system denotes a dynamic movement (flow) of flowthings inside and outside the system. The system structure is defined in terms of the five stages schema as described previously. Let us designate the stages as follows. REC is the receiving stage, PRO is the processing stage, CRE is the creation stage, REL is the releasing stage, and COM is the communication stage. An FM system, S, is defined as follows:

(1) S is a flowthing system such that S ├ {REC, PRO, CRE, REL, COM, [S]}| S

[S] denotes series of sub-systems (e.g., company has several departments),

and flow among stages is defined as:

REC → PRO, REC → REL, PRO → CRE, PRO → REL, CRE → PRO, CRE → REL, REL → COM.

where arrow → denotes flow of flowthings.

├ and | denote a production process where several FM systems (with sub-systems produced in [S]) form one global system.

(2) Let f be the flowthing in S1 and g be the flowthing of S2, then:

• If f is ontologically similar to g then COM → COM in the schemata of S1 and S2 is permitted. That is, if the flowthing is of the same type (e.g., information) then the flow between two systems goes through the communication stages of these systems.

• If f is ontologically not similar to g, then only XXX -->YYY in the schemata of S1 and S2 is permitted, where --> denotes the triggering of flow in another system, and XXX and YYY are stages. That is, any stage in S1 can trigger any stage in S2.

The elements of S (five stages system) are characterized by being exchangeable (received and communicated), creatable, processible, and releasable. Exchangeability means that elements can be imported and exported to other systems. Creatability means that new element can be generated by the system. Proceesibility means that elements are changeable to different forms. Releasability means that elements can be designated as exported outside the system.

In addition to the fundamental characteristics of flow in FM, the following types of possible operations exist in different stages:

1. Copying: Copy is an operation such that flowthing f ⇒ f. That is, it is possible to copy f to produce another flowthing f in a system S. In this case, S is said to be S with copied features, or, for short, *Copy S*. For example, any *informational* schema can be copy S, while physical schemata are non-copying S. Notice that in copy S, stored f may have its copy in a non-stored state. It is possible that copying is allowed in certain stages and not allowed in others.

2. Erasure: Erasure is an operation such that flowthing f ⇒ ∅, where ∅ denotes the empty flowthing. That is, it is possible to erase a flowthing in S. In this case, S is said to

be S with erasure feature, or, for short, *erasure S*. Erasure can be used for a single instance, all instances in a stage, or all instances in S.

3. Canceling: Anti-flowthing f- is a flowthing such that (f- $\cup$ f) $\Rightarrow \varnothing$, where $\varnothing$ denotes the empty flowthing, and $\cup$ denotes the presence of f- and f simultaneously. It is possible that the anti-flowthing f- is declared in a stage, a schema, or a sphere. If the flowthing f triggers the flow of the flowthing g, then the anti-flowthing f- triggers the anti-flowthing g-.

An example of the utilization of these FM features is erasing a flow, as in the case of a customer who orders a product then cancels the order. This may require the cancellation of several flows in different schemata that were triggered by the original order. Copying is an important feature for some types of flowthings such as information. For example, a received order may be stored in the received stage while its copy is passed on to the processing stage. Such a feature may be important in declaring constraints, as in the case of personal information privacy. Similarly, destroying information may be an operation that needs strict control.

Open and closed systems

In classical thermodynamics, an open system exchanges energy, matter, and information with its environment (ecosystem). A closed system exchanges neither matter nor information with its environment. An isolated system is a physical system that does not interact with its environment.

Figure 4 shows a diagram of a closed system in FM. The flowthing is assumed to be a stage-less system. Usually we do not show the flowthing node when we draw a system, only when it is necessary. Notice that, by definition, a system is a system of things that flow; hence, the flowthing is an integral part of the system.

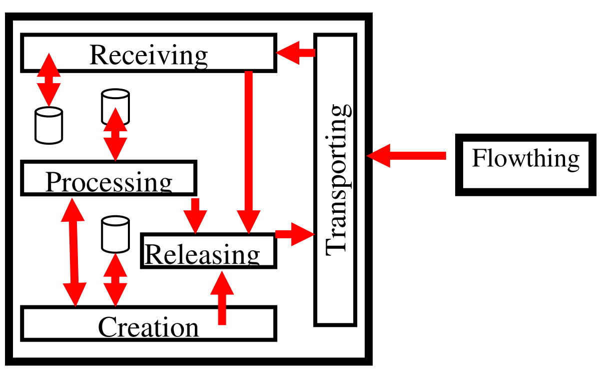

Figure 4. An isolated system in FM.

Figure 5 shows a diagram of an open system. It includes at least two sub-systems where either of them can be the environment. To emphasize the environment, one of the systems can be inside the other.

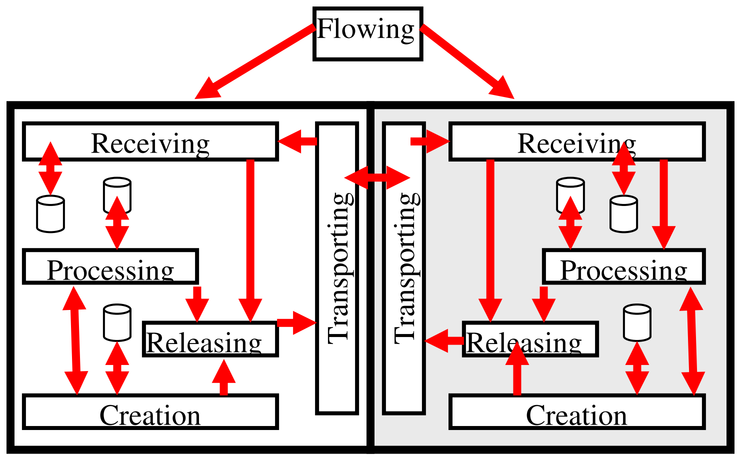

Figure 5. An open system in FM.

Consequently, a closed system in thermodynamics can be represented as a closed system of material and information flows, and an open system as an energy flow system, as illustrated in Figure 6.

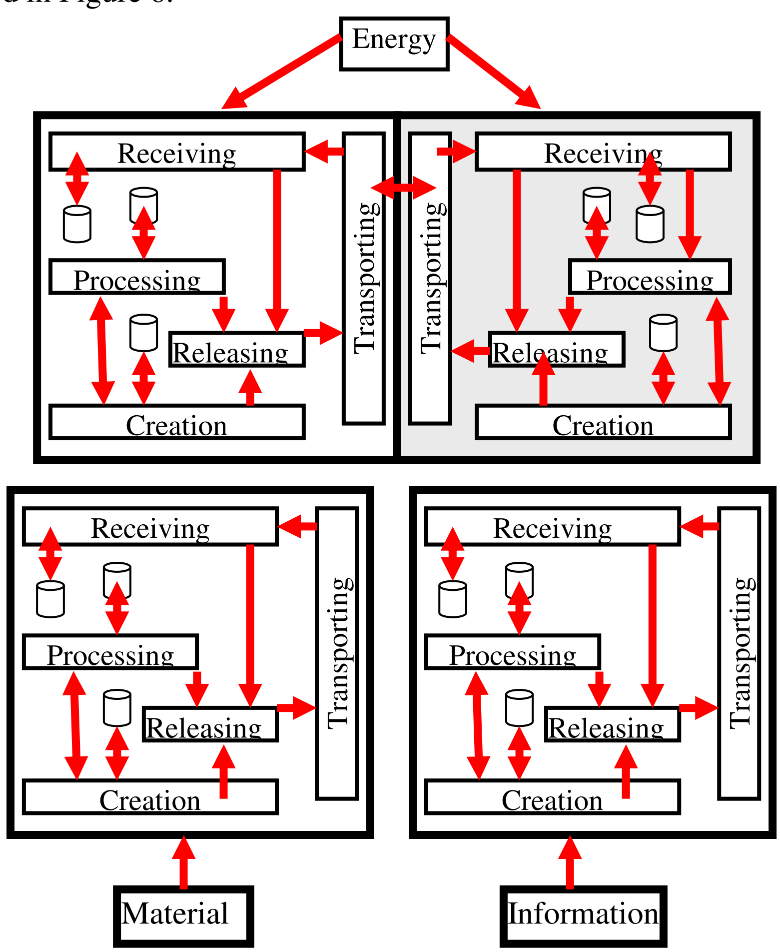

Figure 6. Closed system is "defined" in FM as an open energy flow system, and isolated material and information flow systems.

RE-VISITING SYSTEMS

Typically, systems are described using heterogeneous symbols that represent basic characteristics of any system, including elements, flows, valves, communication, etc. Figure 7 shows such a description of a system with feedback and flows (De Rosnay, 1979).

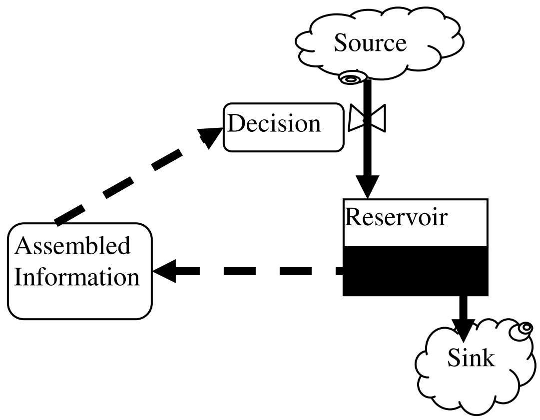

Figure 4. Typical structural characteristics of a system.

The description mixes three types of flows: flow of liquid, flow of information, and implicit flow of action. The flow of action is understood from the box labeled "Decision" and the valve. This means that according to a decision, an action is taken to open or close the valve. Conceptually, this mix of flows is disturbing. Imagine a network with water and electricity coming and/or going from the same (node) source and destination. In Figure 4, the Reservoir is the source of flow of water to the Sink, and simultaneously, the source of information flow to Assembled Information. The information seems to flow directly into the flow of water at the valve. Additionally, it seems that there is a "gap" between the destination of the water at Decision and the valve. The valve represents an action that results from Decision and is directed to the flow of water. The conceptual structure even depends on the special proximity of Decision to the valve to indicate their relationship. The resultant diagram is a rough sketch of related ideas, not appropriate to be called a system, where the mere word "system" gives the impression of reasonably clear components and relationships.

In contrast, in FM, things are precisely modeled. Figure 8 shows three separate flows: water, information, and actions. The liquid enters the liquid flow system at circle 1 through the transporting stage. It flows to the receiving stage (circle 2) and to the reservoir (circle 3).

The access liquid flows back from the reservoir to the release stage (circles 4 and 5), to be transported outside the system (circles 6 and 7). The receiving stage, where the reservoir resides, triggers (circle 8) the creation of information about the liquid level in the informational sphere. This information may be processed (circle 9); accordingly, a decision (information) is made (created) that triggers an action (circle 10). The action (valve control) triggers (circle 11) a module at the transport stage that stops the flow of liquid (refuses to accept more) from outside. Figure 9 shows a version of the FM description. For the sake of simplification, the transporting stage is duplicated in the liquid flow system.

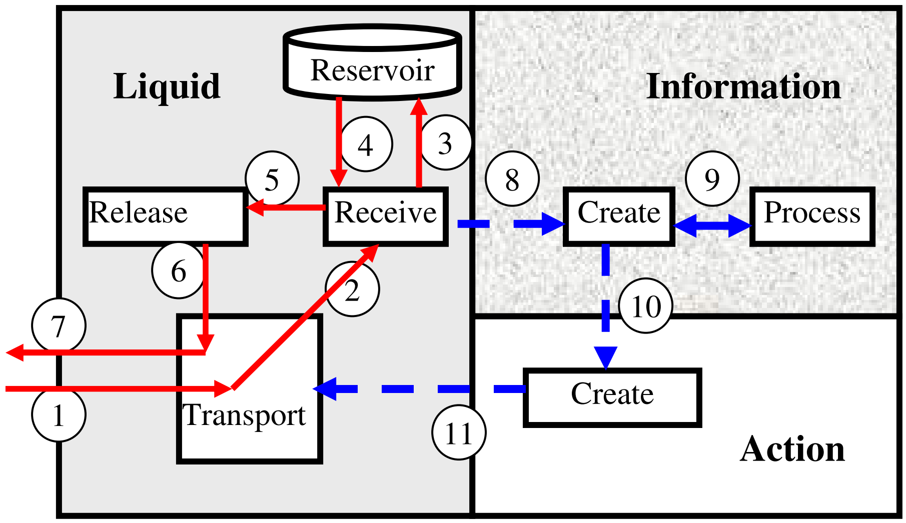

Figure 8. FM description of the system in Figure 4.

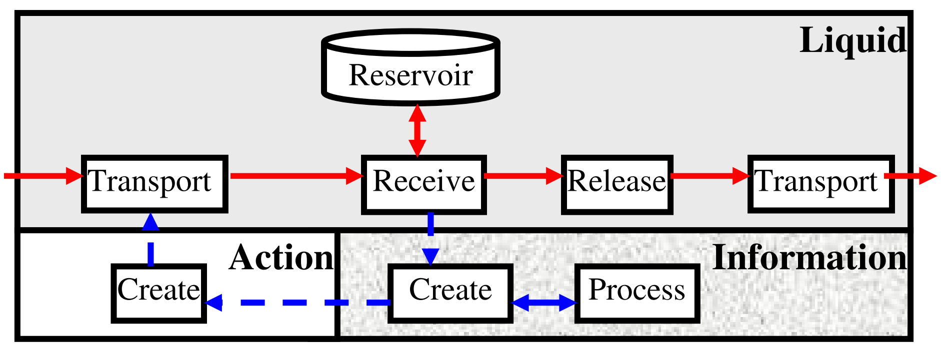

Figure 9. Simplified FM description of the system in Figure

Comparing Figure 6 with the classical diagram in Figure 4, the FM description shows the three flows systematically as separate streams that affect each other. It could also be enhanced by adding additional stages and spheres. The *outside* could be a system that is represented in a similar way. The information sphere can include a receiving stage that represents human control intervention.

MULTI-SPHERE MODELING

According to Smith (2000),

> A System is a set of connected things. A single item is not a system, but when separate things interact together they form a system. Understanding each thing separately is necessary but not sufficient to understand the behaviour of a system. Traditional analyses used a 'Reductionist' approach in that they reduced a complex system to its separate components as a means of understanding. A 'Systemic' approach is 'holistic' in that it seeks to understand the system as a whole.

Smith applies the "systemic" approach to describe "A car as system." A car comprises a few thousand components. Figure 10(a) is a partial view of a system map of a motor car (Smith, 2000). Cars are driven by people. This system could be called "A person driving a car," and is sometimes called a "socio-technical system." Figure 10(b) is a partial view of a system map of this system (Smith, 2000). The purpose here is not to give a complete account of these descriptions; rather, the objective is to show a diagrammatical description in order to contrast it to FM modeling.

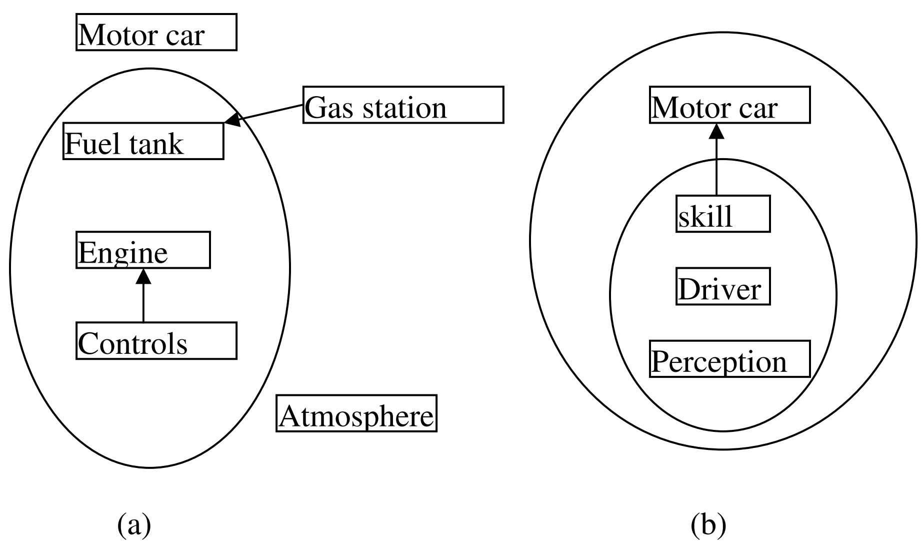

Figure 10. Partial views of systemic descriptions of Motor car and "a person driving a car" given by Smith (2000).

We will show an FM description of some flows in the motor car and its environment system to illustrate the capabilities that can be achieved using such a model. Because of space limitation, we limit our modeling to some flows in the motor car, driver, and gas station systems. Figure 11 identifies these selected modeled systems and their sub-systems.

1. The motor car: We selected three parts of the motor car to model: the engine, the gas pedal, and the gas supply system. The model parts of the engine include two sub-systems: engine physical action, and engine fuel system. The modeled parts of the fuel supply include fuel storage and the fuel gauge system.

2. The driver: The modeled systems of the driver include his/her informational sphere, action sphere, and needs and desires sphere.

3. The gas station: the gas station model is limited to supplying gas.

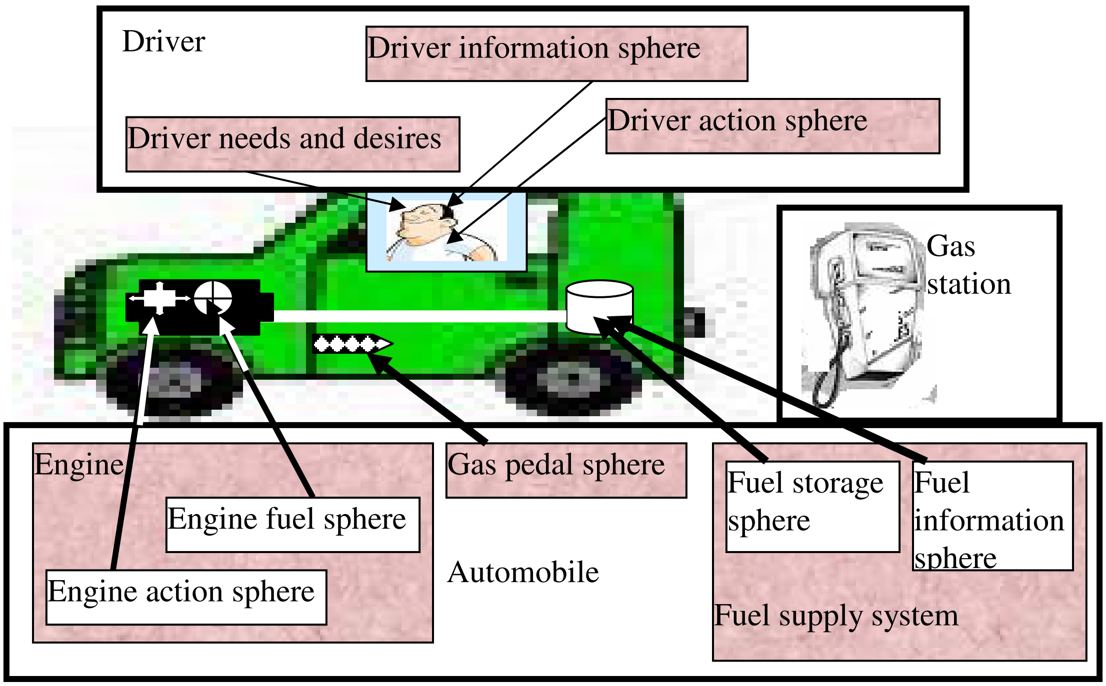

Figure 11. Selected systems that will be described using FM.

Figure 12 shows the resultant model of these systems and sub-systems. It has two main columns: the motor car subsystems on the right, and the driver's sub-systems on the left, in addition to the gas station system at the bottom of the left-hand column (black box).

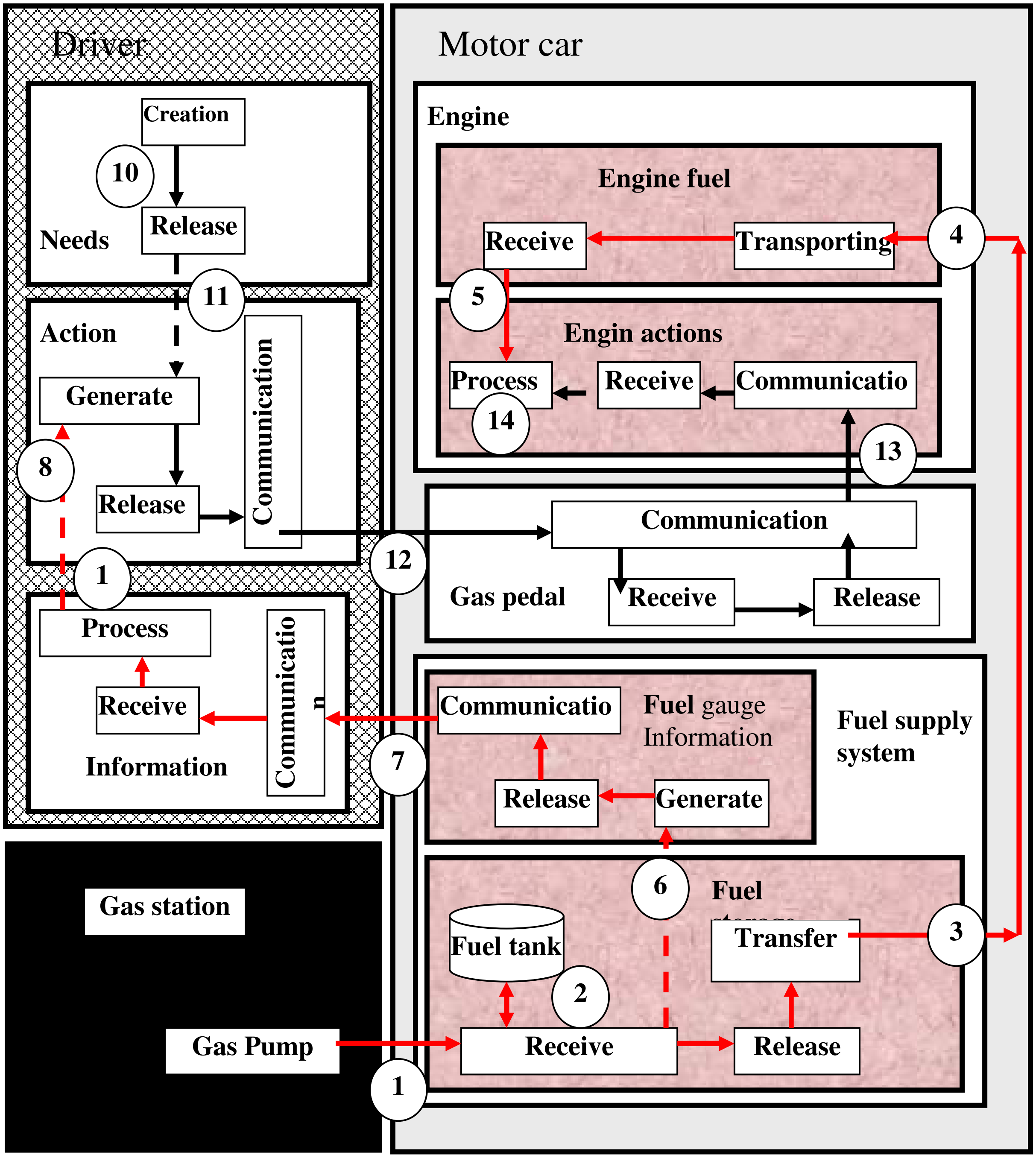

Figure 12. FM description of some flows among motor car, driver, and gas station.

Gas flows from the gas station to the fuel storage of the car (circle 1). It is received in the fuel storage, where it is stored in the car's tank (circle 2). Fuel flows from the tank to the engine (circle 3), where it reaches the engine fuel system (circle 4), is received, and is then fed to the physical engine action (circle 5).

Going back to the fuel tank in the car's fuel supply system, the fuel level in the tank triggers (circle 6) the fuel gauge to generate information about the fuel level. This information is communicated to the driver in his/her informational sphere (circle 7). Now we are in the driver's domain. The driver utilizes the information about the fuel level to take some action (circle 9). We stop at this point of flow and turn our attention to the creation of needs at the top left corner of the figure. Of course we can continue modeling from point 9, for example, the driver processes the information about the fuel level and initiates an action to drive to the nearest gas station, etc.

At the top left side of the figure, in the driver's needs sphere, needs are created (circle 10), hence, they generate an action (circle 11). Notice that triggering does not go through the communication stage because needs do not flow to actions. Rather, needs trigger (dotted arrow) an action. We assume that such actions are concerned with controlling the gas pedal of the car (e.g., increasing or decreasing speed).

The generated action flows to the pedal system (circle 12), which receives it and communicates the action to the engine physical action system (circle 13). In the engine system, the action is "processed," causing change in speed (circle 14).

This conceptual description is a map of different modeled parts connected by different flows of information, fuel, and actions. It can be used for design, educational, and exploratory studies. Notice the uniform application of the five-stages schema for different systems and flows.

ECOSYSTEMS

An ecosystem has been defined as a dynamic system composed of a biotic and abiotic community and its associated abiotic environment. It is a term that originated from biology. Pidwirny (2006) describe ecosystems as follows.

> Ecosystems are composed of a variety of living organisms that can be classified as producers, consumers, or decomposers. Producers or autotrophs are organisms that can manufacture the organic compounds they use as sources of energy and nutrients. Most producers are green plants that can manufacture their food through the process of photosynthesis. Consumers or heterotrophs get their energy and nutrients by feeding directly or indirectly on producers. We can distinguish two main types of consumers. Herbivores are consumers that eat plants for their energy and nutrients. Organisms that feed on herbivores are called carnivores. Carnivores can also consume other carnivores. Plants and animals supply organic matter to the soil system through

shed tissues and death. Consumer organisms that feed on this organic matter, or detritus, are known as detritivores or decomposers. The organic matter that is consumed by the detritivores is eventually converted back into inorganic nutrients in the soil. These nutrients can then be used by plants for the production of organic compounds.

Pidwirny (2006) introduces a graphical model, shown in figure 13, to describe the major ecosystem components and their interrelationships.

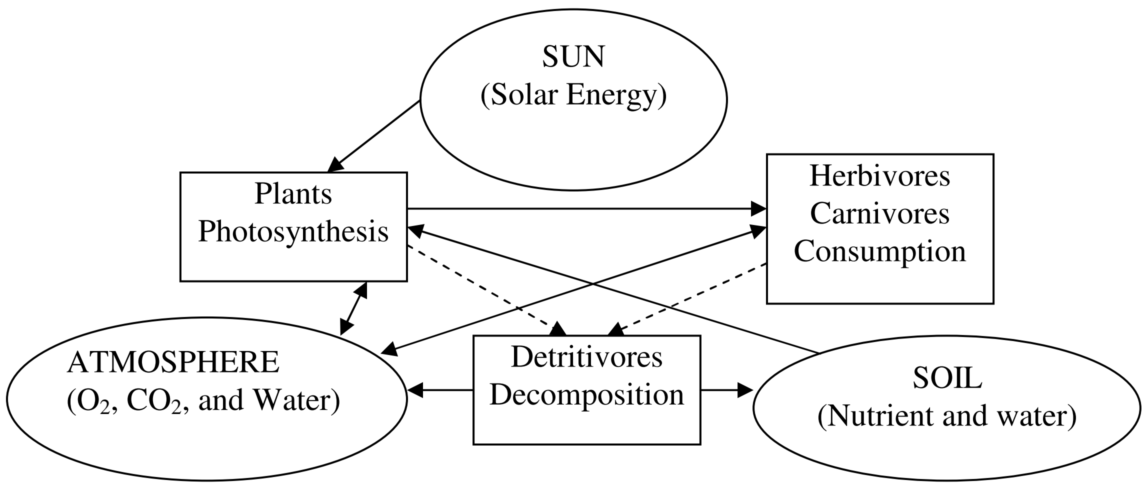

Figure 13. Relationships within an ecosystem as described by Pidwirny (2006).

This description may be used as an initial description of the ecosystem; however, it is conceptually disturbing since the arrows represent many types of flows. For example, it may be accepted that the arrow from the sun to the plants represents flow of energy. However, it is difficult to imagine the thing that flows from Plants to Decomposition. It can include materials such as bodies; then how do bodies flow to the atmosphere? The semantics of the arrow between Decomposition and Atmosphere may indicate "production," that is, decomposed bodies generate gases and water. But this semantics is different from the semantics of the arrow from SUN to Plants, which represents a flow of energy. The best way is to take the arrows in the figure as indicators of relationships among components.

Figure 14 shows a partial view of the corresponding FM description. Certain systems and flows are omitted because of the width of the drawing page. The figure includes the following systems.

1. Sun: with creation, release, and transporting stages of energy.

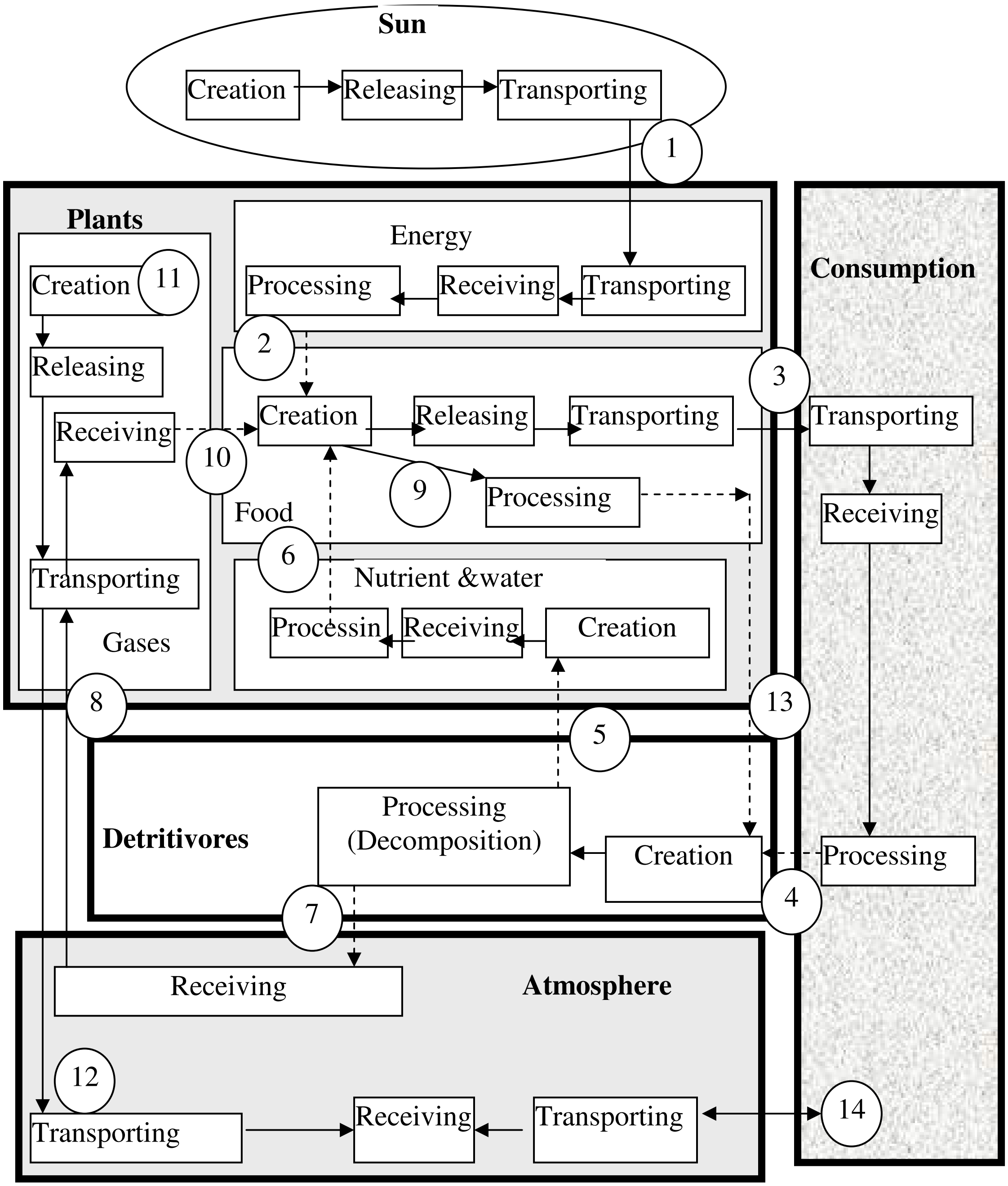

Figure 14. Partial view of FM description of the ecosystem.

2. Plants: The system of Plants has four sub-spheres (systems):

- Energy flow system
- Atmospheric gases flow
- Food (material) flow
- Nutrients & water

3. Consumption
4. Detritivores
5. Atmosphere

Consider starting with the creation of energy in the sun that flows to the energy system of plants (circle 1). Energy is used in internal processing (circle 2) to create materials that flow to consumers (circle 3). The processing of food inside the consumers lead to waste products and, ultimately, their own dead bodies, which end up feeding detritivores (point 4) that that produce Nutrients & water (circle 5) and atmospheric gases (circle 7). Dead plants also feed detritivores (circles 9 and 13).

For simplicity's sake we have not included separate sub-systems for Nutrients & water and gases in the detritivores' system. Nutrients & water are used as food in the food system of the plants (circle 6).

At circle 7, gases are received in the atmosphere. Atmospheric gases flow to the gas system of the plants (circle 8) to be used in manufacturing food (circle 10).

We start now at the "creation" of gases (O_2 or CO_2) in plants (circle 11) where gases flow to the atmosphere (circle 12). The flow of gases between the atmosphere and consumers can be modeled in a similar way; however, we have omitted this flow from the diagram (circle 14).

This FM description is a road map for the whole ecosystem landscape. The repeated application of the five stages schema gives the model a uniformity that is rarely found in modeling complex systems.

CONCLUSION

The flow model separates different types of flow with the possibility that one flow "triggers" another flow. The resultant FM description is suitable for modeling flow-based systems as demonstrated by examples. While FM is still under development, it is clear that it introduces new aspects to conceptual description of systems in the field of systems sciences.

Further research needs to investigate modeling of other types of systems in FM. The exact place of FM among different diagrammatical descriptions also needs to be explored. One point is clear: FM modeling can enhance many of these descriptions. Also, FM seems to reveal a more fundamental structure in systems of things that flow.

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