Middle-East Journal of Scientific Research 22 (4): 502-511, 2014
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2014.22.04.21705

Heraclitean Conception of Control: Exploratory Investigation

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Abstract: The important notion of control has been applied in many disciplines; in fact, the idea of control is so ubiquitous that it is hardly recognized as an independent phenomenon. The main purpose of this paper is to explore the notion of control from a Heraclitean point of view with a proposed flow-based conceptual representation for control systems. The representation is applied to identifying some characteristics of the notion of control. It also used to recast sample models from the literature in order to demonstrate its use as a new form of high-level diagram for better understanding of control systems.

Key words: Conceptual model · Control system · Control definition · Change · State

INTRODUCTION

Control is an important notion related to systems design since it is utilized to maintain performance necessary to achieve the system's objectives. Its function involves monitoring the controlled system in order to adjust operations to maintain variations from objectives within allowable limits. Control encompasses important notions, including feedback, process, loop and stability, that form a foundation for many disciplines such as engineering, science, psychology, biology and economics. It has been successfully incorporated into many applications, ranging from satellite and missile guidance systems to data processing, electrical systems, robotics and prosthetics and its basic ideas are increasingly being applied in other disciplines.

A huge research effort is under way into different applications of control and many books have been written on this topic; thus, it is impossible to give a fair review of the field in this short space. Accordingly, we briefly mention a few resources that address the question, "what is control?", as follows:

- In engineering, Johan *et al*. [1] define control as "the use of algorithms and feedback in engineered systems."
- In management, Robbins and Coulter [2] define control as "the process of monitoring activities to ensure that they are being accomplished as planned and of correcting significant deviations."
- In psychology, Schneider and Shiffrin [3] define a "controlled process" as "a temporary sequence of nodes activated under control of and through attention by, the subject."
- The Merriam-Webster online dictionary [4] defines control as
- The power to make decisions about how something is managed or done
- The ability to direct the actions of someone or something
- An action, method, or law that limits the amount or growth of something

Still, such a central concept is not completely understood. Many terms can apply to vaguely control-like situations, for example, restrict, influence, constrain, affect, modify, manipulate, cause and change. "The problem is that real control is so ubiquitous in the behavior of organisms that it isn't even recognized as a phenomenon" [5]. In the politico-administrative area, Jørgensen [6] declares, "We need more ideas and categories than those offered by conventional control thought in order to 'see' the many control mechanisms existing."

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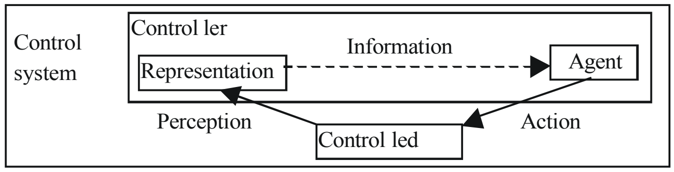

Fig. 1: Control system (from [8]).

In computer science, the focus is on semiotics definitions of control, such as the familiar concept of feedback with two inputs and amplification. Another related definition is built on a combination of descriptive messages (statements) and imperative messages (commands) that create a control relation. A more recent conceptualization of control is given by Turchinal [7]:

> Control is the operation mode of a control system which includes two subsystems: controlling (a controller) C and controlled, S. … The controller C may change the state of the controlled system S in any way, including the destruction of S. The action of S on C is formation of a perception of system S in the controller C.

The controller is a responsible agent and representative states of the controlled objects are identified by perception (Fig. 1). The variables directly affected by the controller are distinguished from the variables perceived by the controller. "The agent compares the current representation with the goal and takes actions which tend to minimize the difference between them" [8] (italics added).

This type of understanding of the notion of control is disputed by Howe [9], however:

The distinction maintained here between the effects of the controller on the controlled and vice-versa is incoherent. Controller's state partly consists of the representation of the controlled. … The only notion that might work is, loosely, that the controller has "influence" over the controlled. … Both determine part of the states of the other. Perhaps what is needed is a more teleological concept of control. [9]

Another conceptualization in this direction is given by Boyd [10]. In this approach, control is related to reducing the range of potential outcomes of the operation of a system or the execution of a process, to a smaller set "which is more favorable (or at least less unfavorable) to the controller."

This paper explores seeking a conceptual base for better understanding of the notion of control. The proposed approach is a high-level description with advantageous features for the requirements level of system development. It could also be useful in education and documentation. The long-term aim is to look beyond current approaches and views of control by moving from the requirements level to the system design level. The material presented here is exploratory in the sense that it is a portion of ongoing research that develops a completely new direction for understanding of control. The philosophical foundation of this work is the notion of fluidity propounded by Heraclitus, a pre-Socratic Greek philosopher who declared that "everything flows." Plato explained this as, "Everything changes and nothing remains still," using the word "change" instead of "flow" [11]. The next section provides background on applications of this approach, called the Flowthing Model, in several areas [12-13]. The section also includes new material related to the model.

Flowthing Model: According to Henrich *et al*. [14].

Anybody having encountered the construction process will know that there is a plethora of flows feeding the process. Some flows are easily identified, such as materials flow, whilst others are less obvious, such as tool availability. Some are material while others are non-material, such as flows of information, directives, approvals and the weather. But all are mandatory for the identification and modelling of a sound process.

The Flowthing Model (FM) can be related to the notion of fluidity propounded by Heraclitus of Ephesus (535–475 BCE), who was a native of Ephesus, Ionia (near modern Kuþadasý, Turkey). He compared change in things to the flow of a river, including the observation that one could not step twice into the same river. FM is a representation of some segment of reality as a web of interrelated flows that cross boundaries of intersecting and nested spheres. This representation is an apparatus that facilitates flowages (acts of flowing). Ingredients in a flowage include flowthings (things that flow) and flow systems (flowsystems). So-called objects, concepts, entities and time are flowthings. A "thing" is defined as a flowthing: "what is created, released, transferred, arrived, accepted and processed" while flowing within and among spheres. In spite of using the term "thing", the fundamental ontology in FM is that "systems are not composed of things, but are rather defined on things and there is a clear distinction between their physical 'thinghood' and logical 'systemhood' properties" [15]. Accordingly, a sphere or subsphere can be any object, any region of logical space that is set apart (mentally) from anything else [15].

A flowthing has a permanent identity but impermanent form. A flowsystem constrains the trajectory of flow of flowthings. A particular flowsystem provides the space/time for happenings and existence of flowthings. To flowthings, the flowsystem is formed of six discontinuities: being created, being released, being transferred, being arrived, being accepted and being processed.

Six Exclusive Stages of Flow: Flows connect six stages that are exclusive for flowthings; i.e., a flowthing can be in one and only one of these six states at a time: Transfer, Process, Creation, Release, Arrival and Acceptance, as shown in Fig. 2. Where appropriate, we can use Receive as a combined stage of Arrive and Accept. These stages are the elementary basic actions. A system manifests itself by engaging in these actions: processing, creating, releasing, receiving and transferring of flowthings. In Fig. 2, we assume irreversibility of flow, e.g., released flowthings flow only to Transfer.

Note that this conceptualization of stages as elementary actions may not coincide with other uses of such terms, e.g., in physics. For example, (model) time and (model) space are simply flowthings in FM that can be created, processed, released, etc…, e.g., a clock is a flowsystem that can create, release and transfer time.

If a system (global sphere) includes a human sphere, this human sphere has subspheres such as money, information, emotions, etc… as flowthings. These flowthings flow in specific "flow channels," changing in form and interacting with outside spheres as shown in Fig. 3, where solid arrows represent flows and dashed arrows represent triggering, e.g., receiving an action (e.g., a hit) triggers emotion (e.g., anger), that in turn triggers a counter action.

The lower-level spheres where the flows occur are called flowsystems; these include, at most, six stages, as follows:

- Arrive: a flowthing reaches a new flowsystem
- Accepted: a flowthing is permitted to enter the system.
- Processed (changed in form): the flowthing passes through some kind of transformation that changes its form but not its identity (e.g., compressed, colored, compared)
- Released: a flowthing is marked as ready to be transferred (e.g., airline passengers waiting to board after completing processing)
- Created: a new flowthing emerges (coming into existence relative to its sphere) in the system (e.g., the processing of a neutron generates a proton, electron and neutrino)
- Transferred: the flowthing is en route to somewhere outside the flowsystem (e.g., packets reaching ports in a router, but still not in the arrival buffer).

An additional stage of Storage can also be added to any FM model to represent the storage of flowthings; however, storage is a generic stage, not specific, because there can be stored processed flowthings, stored created flowthings and so on.

A flowsystem may not need to include all the stages because the other stages are irrelevant, have no impact, or are prohibited, e.g., an archiving (storage) system might use only the stages arrive, accept, release and transfer. Multiple systems captured by FM can interact with each other by triggering interrelated events in their spheres and stages.

Example: Consider a process unit that vaporizes a liquid feed stream which is typically diagrammed as shown in Fig. 4. With FM, this process can be represented as shown in Fig. 5. The liquid flows to the liquid flowsystem (circle 1 in the figure). The steam also flows to the steam flowsystem (2), triggering (3) processing (changing) of the liquid (4). This in turn triggers the creation of vapor (5) that flows to the outside (6). Note that flows do not mix or connect.

Exclusiveness: The exclusiveness of FM stages (i.e., a flowthing cannot be in two stages simultaneously) indicates synchronized change of the flowthing. A flowthing cannot be changed in form and sphere simultaneously. This is a basic systematic representation of change in flowthings. To give a little depth to FM, we offer informal justification for some cases of this exclusiveness of stages.

Exclusiveness of Transferring and Processing: Suppose that a message is distorted while being transmitted (change in form and sphere) and then restored at the destination (using, say, parity-bit correction technique). It can be stated that no change in form (processing) occurred during movement from one sphere to another:

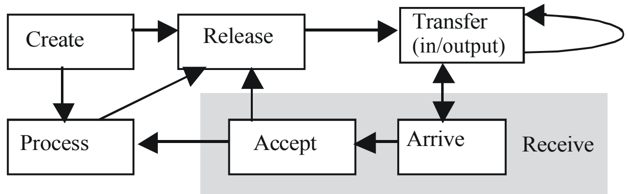

Fig. 2: Flowsystem

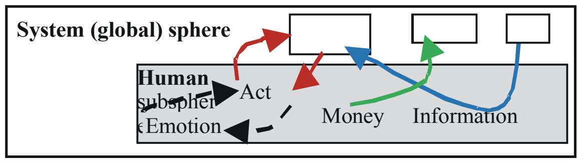

Fig. 3: The sphere “Human” contains subspheres with streams of flowthings that flow among spheres

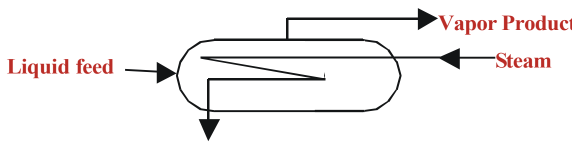

Fig. 4: Process of vaporizing a stream of liquid feed (from [16])

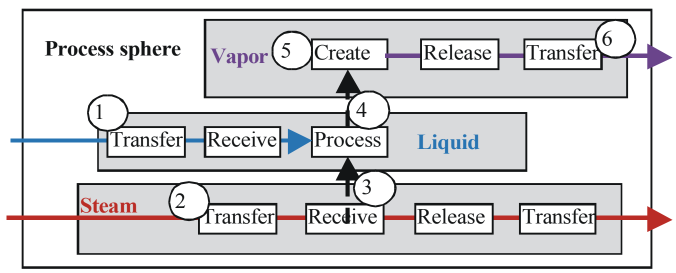

Fig. 5: FM representation of the example process

Source(sphere)->channel(sphere)->destination(sphere).

If a change in form ever occurs, then it must occur while the message is not being transferred; rather this occurred during the Process stage of another sphere (the channel). Thus, the Transfer and Processing stages are exclusive.

Exclusiveness of Creation and Processing: Similarly, no flowthing can be created and change form (be processed) simultaneously. Creation means coming into existence; hence, this transformation is in conflict with change in form (being processed) since the latter requires preexistence.

Also, a flowthing cannot be transferred and arrive at the same point in time and it cannot be received and processed instantaneously[16].

Triggering: Triggering is a stimulus event such as flow initialization, or stopping and continuing of flows. It is one mechanism of change that occurs outside the logical chronological flow of a flowthing through a flowsystem. For example, Creation in a flowsystem needs a jump-tart, something that initiates it, e.g., turning on (i.e., creating) electricity (a flowthing) triggers a flow of heat (a flowthing) and Arrival of a flowthing in a flowsystem can trigger Release of a waiting flowthing in the same flowsystem. This mechanism of sequential triggering is analogous to movies, with a sequence (flow) of scenes changing to another sequence (flow); however, triggering can also jump-start parallel flowsystems.

Triggering is indicated by dashed arrows. Synchronization (e.g., join/fork) and logical (e.g. and/or) notions can be superimposed on the basic FM depiction. For example, the logical AND can be represented by a flowsystem that receives two flowthings, then processes (ANDs) them and creates a new flowthing that is released and transferred as the result of the AND operation. However, for the sake of clarity, such notions will not be represented as flowthings (e.g., representing join by a bar in petri nets).

Spheres and Subspheres: Spheres are conceptual distinctions that split the world into parts [17]. Spheres and subspheres are the structures for flows and flowsystems (flow sphere). If the Danube River is a flowsystem, then the countries, counties, districts, cities, etc. through which it flows are spheres and subspheres. The sphere of the Danube basin is the physical structure of interrelated subspheres of lands, tributaries, cities, factories and so on that span spaces. An enterprise is a sphere structure of interrelated departments, sections and persons (subspheres) with flows of products, papers, e-mails, files, etc. that classify the environment as a structure of activities with common objectives. These spheres and subspheres reduce the space of description, bound the model and increase meaningfulness [18].

If the sphere of a person (say, in the supersphere of an information system) recognizes only two properties, then the world represented in the person sphere is a world in which there are only two properties (closed system assumption). A sphere can have multiple flowsystems in its construction, if needed. It can be an entity (e.g., a hospital and the departments within it; a person or class of persons, e.g., nurses; a computer with one or more components; and so forth), a location (laboratory, waiting room), communication media (channel, wire), … A flowsystem is a subsphere that embodies the stages of the flow; it itself has no subsphere.

Flow refers to the "entrance" of a flowthing into the "context/view" of a sphere; for example, the movement of an artifact along an assembly line eventually leads to its arrival in the spheres of several robots, as shown in Fig. 6.

In general a stream that includes several occurrences of triggering or mixed flows and triggering is called propagation, e.g., there are two propagations from assembly line to Robots 1 and 2 in Fig. 6.

Change and Control: In preparation for our conceptualization based on FM, this section analyzes the notion of change as a fundamental concept in understanding of control. As we will see later, our definition of control using FM is based on the concept of change.

Typically, change is defined as "an alteration in the properties of some enduring thing," or "a sequence of states" [19]. The concept of change has a long history in philosophy. Aristotle thought that every change involves three essential ingredients: a pair of states and a subject undergoing the change: "something, x, goes from being F to being not F, or vice versa" [20]. According to Karl Popper, "Heraclitus was the philosopher who discovered change" [21].

Change happens to flowthings and to spheres. The ingression of a change in a flowthing happens in several ways, including:

- Change in sphere (e.g., regions in the world) through being released, transferred and received from one sphere to another.
- Change in existence through being created (emerging) or de-created (extinguished). An a priori snapshot of the sphere of the creation does not contain the flowthing and an a posteriori snapshot contains it.
- Change in the form of one or more features through being processed, e.g., shape, color, size.

A change to a flowthing can also be the result of triggering, as will be discussed later.

Instant of Change: Triggering may also indicate an instant of change between flowsystems. Changing the gear in a parked car involves an action in the gear sphere that triggers the creation of movement in the car sphere. This instant of change contrasts with the transfer-transfer instant of change of sphere (e.g., electricity from a wire to a computer), where such an instant is divided into two stages: transfer in the source sphere (wire clamp) and another transfer in the receipt sphere (computer port). FM represents a change in terms of change of flowsystems where the instant of change (boundary between instantaneous spherical slices) has its conceptual place.

A change itself is a flowthing that has its own flowsystem, since a change can be created, processed, released, transferred and received. This will be illustrated in a later example.

Eliminating Change: If the given requirements of a system recognize change as an element of interest in the system, then change is modeled as a flowthing. For example, it is required to report a change as follows:

At 11:00:23 + change occurs,
At 11:10:42 change is eliminated.

Fig. 7 shows this case in terms of a classical problem of process control.

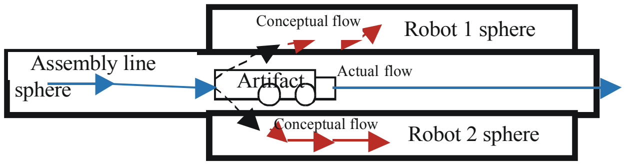

Fig. 6: Illustration of two conceptual flows triggered by the actual flow of an artifact

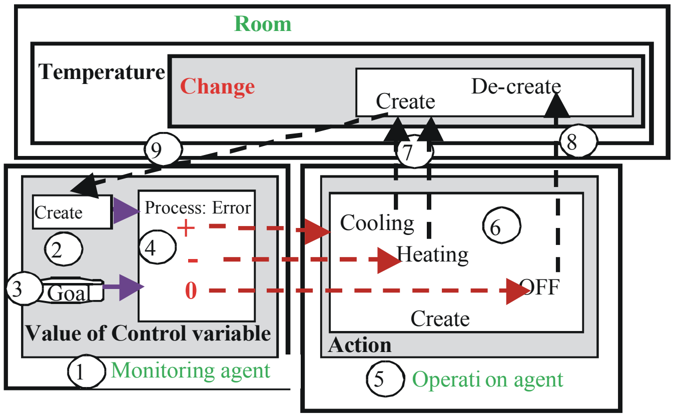

Fig. 7: Eliminating change

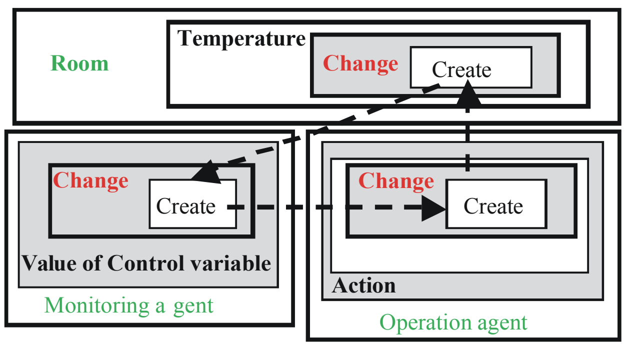

Fig. 8: Change occurs in all spheres

In the figure, a monitoring agent (circle 1, e.g., a thermostat) creates a value (2, e.g., room temperature) and compares it with a goal value (3) to calculate ERORR (4). This triggers an operation agent (5) to adjust its action (6), e.g., produce cold or hot air; thus causing change (7) or eliminating change from the desired value (8). This triggered adjustment in turn causes the monitoring agent, e.g., thermostat, to create a new value (9).

Note that this example of controlling room temperature gives us a first characterization of control: it implies a propagation of changes among spheres in a loop (Fig. 8). Note that a change is a flowthing.

To distinguish control-related change from other types of change that include flows and propagation, other features can be deduced conceptually such that propagation in control implies,

- Mandatory change: If the temperature changes, then the thermometer changes; hence, the action changes, which in turn causes the temperature to change.
- Presence of an equilibrium focus for change in each propagation: in the example discussed,

The temperature in the hemostat oscillates around zero degrees of error,

The temperature in the room fluctuates around maximum and minimum values,

The operating agent alternates between certain amounts of work of cooling and heating, just as inhaling and exhaling alternate between taking air in and letting it out.

The global goal of the system emerges from the loop of these equilibrium focuses of change: Fixing the room temperature at a specific degree.

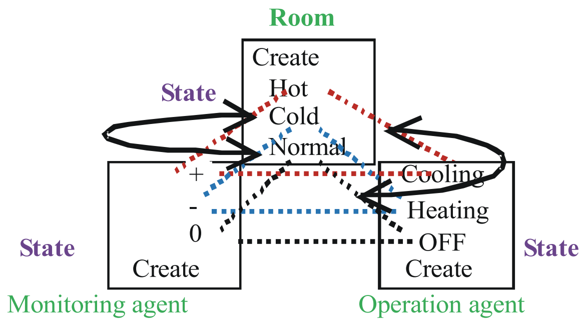

Fig. 9: States tied together

The example can be applied in terms of states of systems (Fig. 9). States are also themselves flowthings that can be created and processed (e.g., a TV commercial for a soft drink might trigger the creation of a state of thirsty in the viewer that is processed to influence the viewer to buy that drink). The figure shows three tri-states (physical states in different spheres occurring together). The two arrows indicate an oscillation among the tri-states. These tri-states can be considered states of the sphere (environment) that encompasses the three spheres in the example, where

(+, Cooling, Hot) <=> (0, OFF, Normal))
(-, Heating, Cold) <=> (0, OFF, Normal))

The global sphere has n global states where n is the number of participating flowsystems (three in the example).

Definition of Control: Now, after examining a sample control system, we can embark on a mission to explore the notion of control using the FM representation. As stated previously, the FM representation depicts an apparatus that creates, processes, releases, transfers and receives flowages (acts of flowing). As observed in the room temperature example, there are equilibrium focuses for change in each propagation. The global goal of the system emerges from the loop of these equilibrium focuses of change. That is, when these three systems "work together" as specified in the loop of change, then control with its goal emerges as a meta-system of control (we call it a global system). Consequently, control is an apparatus that maintains changes in order to reach certain goals (Fig. 10).

The interesting aspect of this discussion is that it is possible to create a representation of the sphere of the control system by using FM (Fig. 11).

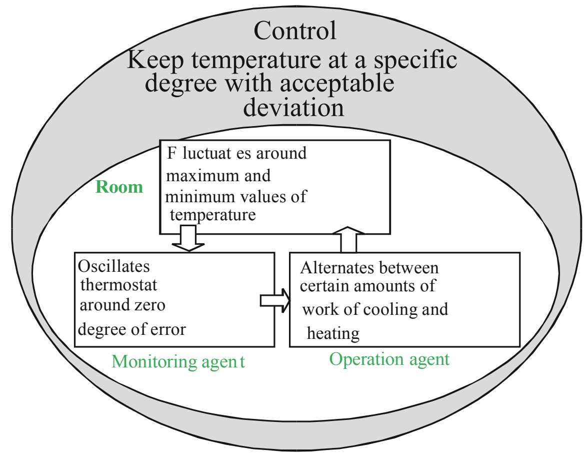

Fig. 10: Control is a global apparatus that emerges from the loop of subsystems

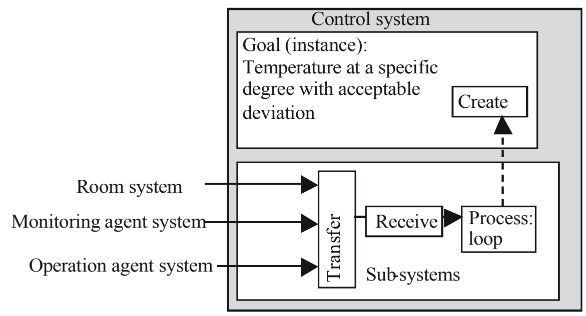

Fig. 11: The control system sphere

Thus, FM can be used to specify the control system and its meta-system. Note that the subsystems that participate in control phenomena have become flowthings in the control sphere of the meta-system. This is an example of spheres in one system that are flowthings in another system. This is an FM realization of Heraclitus' declaration that "everything flows."

Sample Application: Now that we have a new descriptive base for characterizing control systems, this section explores applying it to models described in the literature. The purpose is twofold:

- Recasting these models in terms of FM representation provides a new form of diagram that can be compared side by side with them to examine such features as completeness, abstractness (vs. implementation-based details) and clarity, to be used for communication (with users, implementers, …), documentation and teaching purposes.

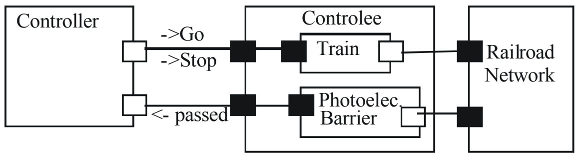

Fig. 12: A simple controller/controlee scenario (partial from [21])

- Developing an FM representation for control systems may uncover new characteristics of the notion of control that help in clarifying and analyzing the concept.

In the communication field, according to Von [22], “It is the aspect of control in a communication relationship, which lets us distinguish different types of communication.” Three elementary types of communication between two communicating parties are distinguished:

- Control-oriented: only one side exerts control
- Data-oriented: no side exerts control
- Protocol-oriented communication: both sides exert control

Here, control is defined as “the directed exertion of influence on the behavior of the communication partner” [22].

Von [22] utilized the so-called ROOM (Real-time Object-Oriented Modeling) diagram to represent these types of control. This type of diagram can be used in conjunction with Unified Modeling Language (UML). Fig. 12 shows a simple scenario of a control-oriented communication relationship in which the controller and controlee are connected by two bonds of communication. “The ROOM protocols are defined from the perspective of the controlee, which is indicated by the “black” ports on the controlee’s side. There is a photoelectric barrier attached to the railroad network that sends out a message as soon as a train passes by” ” [22].

The FM representation (Fig. 13) provides a more complete conceptual depiction of the control notion embedded in such a diagram. Examining the ROOM diagram, it is apparent that the structural conceptualization does not reflect the structure of the system. Structure is a very important framework in which to design control in the system. According to Leigh [23], control involves structural properties and it requires system representations without unnecessary detail that still preserve connectedness. “The masterly map of the London Underground system is an everyday example of how useful a representation can be when it has been stripped of all properties except that of connectedness… Connectedness is a concept from topology” [23]. The design of a control system starts with a map of the system, including boundary parts and places of subsystems, that provides a background for superimposing a controlling mechanism. How do you design traffic controls without a map of the city?.

The ROOM diagram is overly abstracted in a way that approaches incompleteness. The railroad network is not really the physical network of track; rather, it is the global sphere of the system that includes trains and a photoelectric barrier. It is obvious that in this scenario the Railroad sphere encompasses only the Train and Photoelectric barrier spheres. The Train sphere includes the train, a physical flowsystem that also functions as a flowthing, as shown in Fig. 13 (circle 1), which is received at its station from a parking place (not shown). The Train sphere as a conceptual environment also includes the state of the train (2 - STOPPED-GOING), its location (3) and command signals (4). Similarly, the photoelectric barrier (5) includes two flowsystems: location (6) and message (7).

Thus, starting at circle 1, the train moves as a flowthing, triggering its changing location (8) that are captured (9) by the photoelectric barrier, triggering creation of a message that flows to the controller (11), where it is processed (12) to trigger the creation of a control command (13). The STOP/GO command flows to the Train sphere (14) where it is received (15) to change the state of the train: STOP or GO (16). This series of responses affects (17) the processing (movement) of the (physical) train. We, as designers, also need to add another triggering mechanism at the very beginning to start the flow of the train (18), a detail that does not appear in Von’s original description [22].

Of course The FM representation is more “complex” than the ROOM description. No apology is made for such a feature: it would be like comparing a detailed blueprint with a simple sketch showing floors in a building; however, the “complexity” here is superficial as long as one follows the systematic description of spheres, flowsystems and flows with basic stages in FM[23].

From the FM diagram emerges the main characteristic of control propagations (flows and triggering) that follow each other in sequence as shown in Fig. 14. Commands from the controller change the state of the

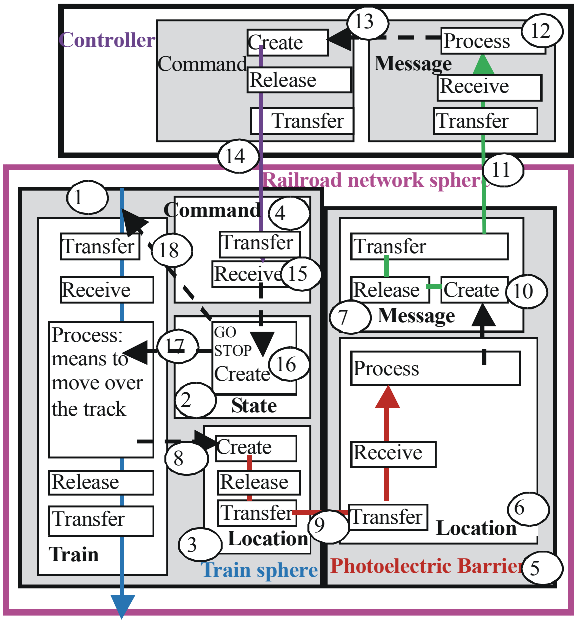

Fig. 13: FM representation of the controller/controlee scenario

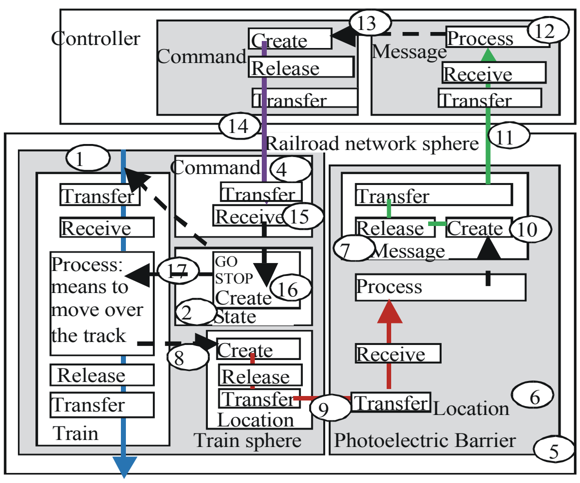

Fig. 14: Propagations in the controller/controlee scenario

train that change the view of the photoelectric barrier whose messages change the commands when the controller is a human being.

The global sphere has a fixed number of states, e.g., (Command: stop, Train: stopping, Barrier: stoppage seen), (Command: go, Train: moving), (barrier: no train in view), etc.

CONCLUSION

This paper has explored the notion of control from the Heraclitean point of view through the proposal of a flow-based conceptual representation for control systems. The representation is applied to sample models in order to demonstrate it as a new form of high-level diagrammatic representation that can be used to enhance understanding of control systems. This investigation is exploratory; nevertheless, the approach seems to present worthwhile concepts that deserve discussion and further investigation.

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