



Experiential Networked Intelligence (ENI); Overview of Prominent Control Loop Architectures (standards.iteh.ai)

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) Experiential Networked Intelligence (ENI).
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Modal verbs terminology

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Executive summary

The present document specifies a high-level functional abstraction of the ENI System Architecture in terms of Functional Blocks and External Reference Points. This includes describing how different classes of systems interact with ENI. Processes, models, and detailed information are beyond the scope of the present document.

1 Scope

The purpose of the present document is to provide information on prominent control loop architectures that can be used in modular system design. This will be applied to the ENI reference system architecture (and any other applicable ETSI reports and standards). The present document will emphasize control loops that are adaptive and cognitive.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

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The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

- iTech STANDARD PREVIEW
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- [i.1] ETSI GS ENI 005 (V2.1.1): "Experiential Networked Intelligence (ENI); System Architecture".
- [i.2] Strassner, J., Agoulmine, N., Lehtihet, E.: "FOCALE - A Novel Autonomic Networking Architecture", ITSSA Journal 3(1), 64-79, 2007.
- [i.3] Boyd, J.R.: "The Essence of Winning and Losing", June, 1995.
- [i.4] Strassner, J.C.: "Knowledge Representation, Processing, and Governance in the FOCALE Autonomic Architecture", book chapter, 2011, Elsevier.
- [i.5] Strassner, J.: "Policy-Based Network Management", Morgan Kaufman, ISBN 978-1558608597, September 2003.
- [i.6] MEF 78.1: "MEF Technical Specification: MEF Core Model", Strassner, J., editor, July 2020. .
- NOTE: Available at <https://www.mef.net/resources/mef-78-1-mef-core-model-mcm/>.
- [i.7] IBM® Autonomic Computing White Paper: "An architectural blueprint for autonomic computing".
- NOTE Available at <https://www-03.ibm.com/autonomic/pdfs/AC%20Blueprint%20White%20Paper%20V7.pdf>.
- [i.8] Strassner, J., van der Meer, S., Won-Ki Hong, J.: "The design of an Autonomic Element for managing emerging networks and services", International Conference on Ultra Modern Telecommunications, 2009.
- [i.9] Minsky, M.: "The Society of Mind", Simon and Schuster, New York, 1988.
- [i.10] R. Mitchell, J. McKim: "Design by Contract, by Example", Addison-Wesley, 2001, ISBN 0201634600.
- [i.11] S. van der Meer: "Architectural Artefacts for Autonomic Distributed Systems - Contract Language", in 6th IEEE Workshop on Engineering of Autonomic and Autonomous Systems (EASe), April 14-16, 2009.

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the terms given in ETSI GS ENI 005 [i.1] and following apply:

abstraction: hiding of unnecessary details to focus on data and information that is relevant for defining a particular concept or process

agent: computational process that implements the autonomous, communicating functionality of an application

architecture: set of rules and methods that describe the functionality, organization, and implementation of a system

cognition: process of understanding data and information and producing new data, information, and knowledge

- **cognition model:** computer model of how cognitive processes, such as comprehension, action, and prediction, are performed and influence decisions

context: collection of measured and inferred knowledge that describe the environment in which an entity exists or has existed

decision making: set of processes that result in the selection of a set of actions to take from among several alternative possible actions

domain: collection of Entities that share a common purpose

NOTE 1: Each constituent Entity in a Domain is both uniquely addressable and uniquely identifiable within that Domain. This is based on the definition of an MCMDomain in [i.6].

- **administrative domain:** Domain that employs a set of common administrative processes to manage the behaviour of its constituent Entities. This is based on the definition in [i.6].
- **management domain:** Domain that uses a set of common Policies to govern its constituent Entities

NOTE 2: A Management Domain refines the notion of a Domain by adding three important behavioural features:

- 1) it defines a set of administrators that govern the set of Entities that it contains;
- 2) it defines a set of applications that are responsible for different governance operations, such as monitoring, configuration, and so forth;
- 3) it defines a common set of management mechanisms, such as policy rules, that are used to govern the behaviour of MCMMManagedEntities contained in the MCMMManagementDomain.

This is based on the definition of an MCMDomain in [i.6].

entity: object in the environment being managed that has a set of unique characteristics and behaviour

NOTE: Objects are represented by classes in an information model.

formal: study of (typically linguistic) meaning of an object by constructing formal mathematical models of that object and its attributes and relationships

knowledge: analysis of data and information, resulting in an understanding of what the data and information mean:

NOTE: Knowledge represents a set of patterns that are used to explain, as well as predict, what has happened, is happening, or is possible to happen in the future; it is based on acquisition of data, information, and skills through experience and education.

- **inferred knowledge:** knowledge that was created based on reasoning, using evidence provided

learning: process that acquires new knowledge and/or updates existing knowledge to optimize a function using sample observations

logic: formal or informal language that evaluates a conclusion based on a set of premises

model: representation of the entities of a system, including their relationships and dependencies, using an established set of rules and concepts:

- **data model:** representation of concepts of interest to an environment in a form that is dependent on data repository, data definition language, query language, implementation language, and/or protocol

NOTE 1: This definition is taken from [i.6].

- **information model:** representation of concepts of interest to an environment in a form that is independent of data repository, data definition language, query language, implementation language, and protocol

NOTE 2: This definition is taken from [i.6].

Model-Driven Engineering (MDE): approach in which models are central to all phases of the development and implementation processes

ontology (for ENI): language, consisting of a vocabulary and a set of primitives, that enable the semantic characteristics of a domain to be modelled

policy: set of rules that is used to manage and control the changing and/or maintaining of the state of one or more managed objects

semantics: study of the meaning of something (e.g. a sentence or a relationship in a model)

situation: set of circumstances and conditions at a given time that may influence decision-making:

- **situation awareness:** perception of data and behaviour that pertain to the relevant circumstances and/or conditions of a system or process, the comprehension of the meaning and significance of these data and behaviours, and how processes, actions, and new situations inferred from these data and processes are likely to evolve in the near future

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3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

COM	Control, Orchestration and Management
COMPA	Control, Orchestration, Management, Policy and Analytics
DE	Decision Element
ESB	Enterprise Service Bus
FB	Functional Block
FOCALE	Foundation - Observe - Compare - Act - Learn - rEason
FSM	Finite State Machine
GANA	Generic Autonomic Networking Architecture
IBM®	International Business Machines
KP	Knowledge Plane
MAPE	Model-Analyse-Plan-Execute
MAPE-K	Model-Analyse-Plan-Execute-Knowledge
MDE	Model-Driven Engineering
ME	Managed Element
ONIX	Overlay Network for Information eXchange
OODA	Observe-Orient-Decide-Act
XML	eXtensible Markup Language

4 Prominent Control Loop Architectures

4.1 Introduction

Most control loop architectures for adaptive and cognitive systems use both feedback (and feedforward) mechanisms. These control loop signals play a critical role in not just stabilizing the system, but more importantly, providing mechanisms for the system to learn experientially. For example, a simple feedback loop consists of taking past interactions with the environment and combining them with current information to guide current and future interactions.

4.2 Definition

A control loop is a mechanism that senses the performance of an object or process being controlled to achieve desired behaviour. ENI is concerned with different types of closed control loops, where the controlling action is dependent on feedback from the object or process being controlled. In other words, closed loops use feedback to monitor and adjust the behaviour of a system to achieve one or more goals.

4.3 Types of Control Loops

4.3.1 Open

An open control loop is a control loop whose controlling action is independent of the output of the object or process being controlled. This type of control loop does not link the control action to the object or process being controlled (it simply continues to apply the control action). This type of control loop will likely not be used in the ENI system.

4.3.2 Closed

A closed control loop is a control loop whose controlling action is dependent on feedback from the object or process being controlled. This type of control loop measures the difference between the actual and desired values of a set of variables to adjust a set of parameters to change the behaviour of the system to bring the actual value closer to that of the desired value.

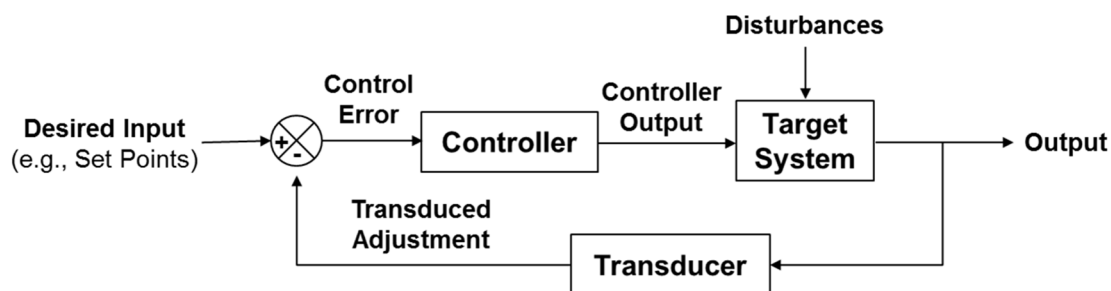


Figure 4.3.2-1: An Exemplary Closed Control Loop

4.3.3 Hierarchical Closed

A hierarchical closed control loop is a control loop that is organized in the form of a tree. This organization enables different decisions to be made by different nodes in the tree. In general, there is a set of supervisory closed control loops that allocate tasks to subordinate closed control loops. Each subordinate closed control loop performs its tasks and returns its result to its superordinate closed control loop. Advanced examples enable one of a group of designated closed control loops to take control of the hierarchy dependent on goals and the environment. This is an example of a self-organizing hierarchical closed control loop.

In general, the topmost closed control loop reasons about an abstract world model; its subordinate closed control loops reason about increasingly more specific models, or portions of models.

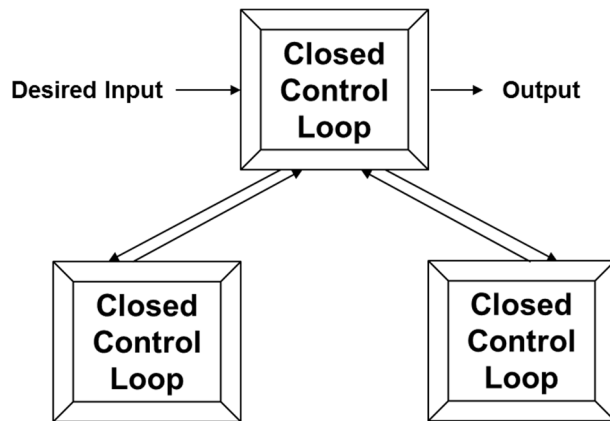


Figure 4.3.3-1: An Exemplary Hierarchical set of Closed Control Loops

4.3.4 Distributed Closed

A distributed closed control loop is a closed control loop whose components are physically distributed among different locations. Each component in a distributed closed control loop uses a message passing mechanism to communicate with one or more other components of the distributed closed control loop.

4.3.5 Adaptive Closed

An adaptive closed control loop is a control loop whose controlling function adapts to the object or process being controlled using parameter that are either unknown and/or vary over time. The parameters may be defined using a model that defines the desired closed loop performance, or statistical analysis to build a mathematical model from measured data.

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4.3.6 Federated Closed

A federated closed control loop is a set of semi-autonomous closed control loops that use formal agreements to govern their interaction and behaviour. This includes rules to admit new members of the federation, as well as rules governing the visibility and types of information that can be shared with other members of the federation. Each closed control loop operates on the same goal using its own local data. Decisions from each closed control loop are then aggregated and published.

4.3.7 Cognitive Closed

Cognition is the process of understanding data and information and producing new data, information, and knowledge. A cognitive closed control loop selects data and behaviours to monitor that can help assess the status of achieving a set of goals, and produce new data, information, and knowledge to facilitate the attainment of those goals.

4.4 Prominent Control Loop Architectural Styles

4.4.1 OODA

Col. John Boyd's control loop [i.3], [i.4] and [i.5] consists of four phases: Observe, Orient, Decide and Act (OODA). It is shown in Figure 4.4.1-1 which is drawn to emphasize how orientation shapes observation, decision, and action. While the loop appears to be sequential, this is merely for convenience. The orientation step is critical, as it determines how observations, decisions, and actions are performed. Hence, observation, orientation, and action occur simultaneously and continuously. As Boyd observed, people act according to how they perceive the world, as opposed to how the world really is.

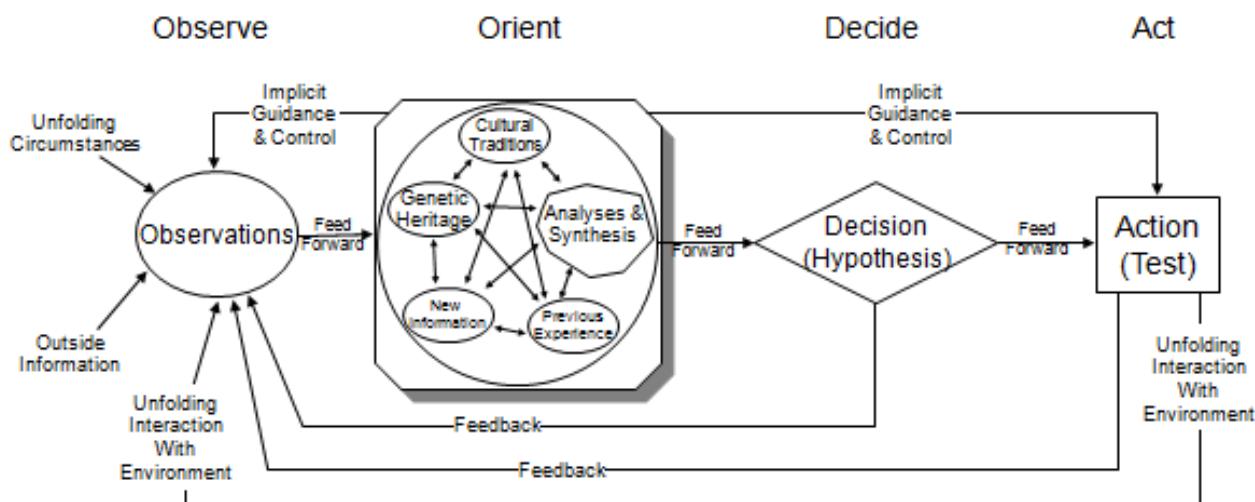


Figure 4.4.1-1: The OODA Control Loop

One of the strongest features of the OODA loop is to initiate or modify actions in response to observed events. If this can be transformed into a machine-understandable form, then formal logic can be applied to examine all different concurrent options to arrive at the best plan to achieve the goals of the mission. This is implemented in FOCAL, which stands for Foundation - Observe - Compare - Act - Learn - Reason; it is an adaptive and cognitive control loop (see [i.2] and [i.4]).

In stark contrast to other control loop architectures, OODA is a set of *interacting* loops, where observations in the current context are filtered (the orient phase) to make them relevant.

The OODA loop was the inspiration and foundation for FOCAL, which is an enhanced version of OODA that features the addition of cognition.

4.4.2 MAPE-K

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In [i.7], IBM® (International Business Machines) defined the Monitor-Analyze-Plan-Execute, or MAPE, control loop. Since all 4 functions depend on the Knowledge function, it is called Model-Analyse-Plan-Execute-Knowledge (MAPE-K). It is shown in Figure 4.4.2-1.

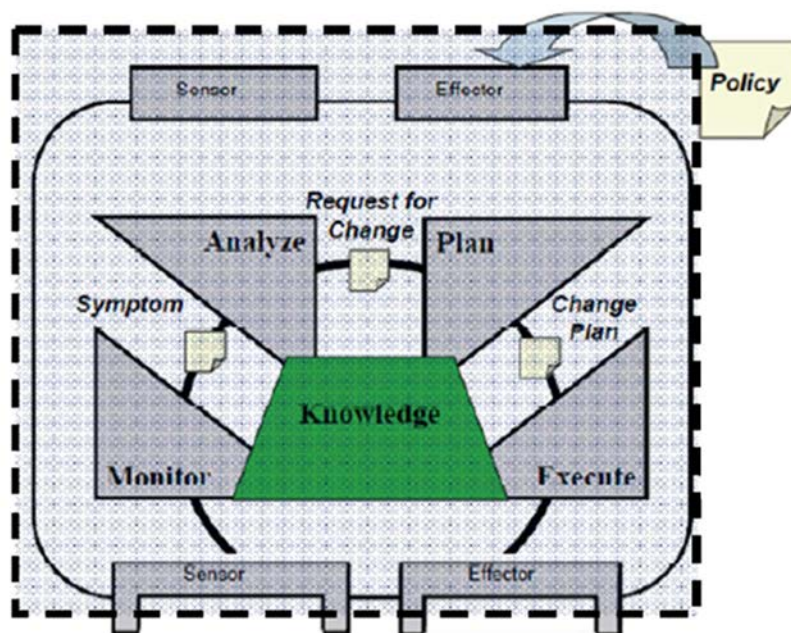


Figure 4.4.2-1: The IBM MAPE-K Control Loop