Awareness-based Couplings of Intelligent Agents and Other Advanced Coupling Concepts for M&S

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Abstract: This study is a sequel of a recent publication where the coupling concepts as well as the advantages of coupling of declarative models were clarified. In this article, the basic concepts of simulation model coupling is reviewed. Advanced input concepts, including context-mediated perception, are elucidated. Synergy of agents and simulation is revised. Awareness-based couplings of intelligent agents are explained. Other advanced coupling concepts clarified include: deliberation-based coupling, introspection-based coupling, anticipation-based coupling, and model/real-system coupling.

1 INTRODUCTION

System theoretic formulation of coupling of component models was first introduced in the seminal work of Wymore (1967) on mathematical theory of systems engineering. The concept allows the formulation of input-output relationships of component-based systems as well as systems of systems. The first application of system coupling in simulation modeling was published by Ören (1971) for GEST – the first system-theory-based declarative simulation modeling language (for continuous and for piece-wise continuous system modeling). In a recent article, a systematic and comprehensive view as well as advantages of hard couplings of declarative simulation models was elaborated by Ören (2014). The concept of coupling has been successfully applied to discrete event system specification (DEVS) by Zeigler (1984) and many other researchers who use and/or contribute to the DEVS formalism. What has been expressed and achieved until now can be labelled as hard coupling as well as conventional coupling.

In this article, our aim is to elaborate on soft coupling and extend the coupling concept for use in modeling and simulation with autonomous and quasi-autonomous intelligent systems. More specifically, promising possibilities of awareness-based coupling of intelligent software agents are pointed out. We will examine soft couplings under two dimensions: proximity and activation. Proximity will be classified in terms of the cognitive, conceptual, and physical spaces, and to define activation, we will review the "input" concept.

In this article the following is done:

(1) Fundamental concepts of model coupling are briefly reviewed in Section 2. Model coupling is basically input-output relationship of atomic or resultant of already coupled models. As such, model coupling represents communications of component models.

(2) To explore several types of communications hence several types of inputs as bases for generalized coupling concepts, non-conventional types of inputs to simulation models, such as (i) cognitive inputs (perception, introspection, and anticipation), (ii) sensations and especially (iii) chemical signals (pheromones) are covered, in Section 3. Perception, introspection, and anticipation (of both external and internal knowledge) form also basis for machine awareness. In information processing, the information traces would have similar functions as pheromones in nature.

(3) Highlights and importance of the several types of synergy of software agents and simulation (which lead to agent-directed simulation) are noted in Section 4.

(4) In Section 5, three types of awareness-based couplings, i.e., perception-based, introspection-

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based, and anticipation-based couplings of software agents as well as other advanced types of couplings are elaborated on.

(5) In Section 6, two types of coupling of simulations and real systems are explained.

(6) Finally, in Section 7, we express our conclusion about this very important and promising research area and outline our future activities.

Over 90 terms denoting several types of couplings of simulation models are listed in an appendix.

2 MODEL COUPLING: BASICS

Some of the papers on simulation model coupling published by one of the authors are (Ören, 1971, 1984, 2014). Since in the last one, the coupling concept is explained in detail, here we cover only very basic concepts to provide the foundation for more advanced types of couplings. Figure 1, adopted from (Ören, 2014) depicts a typical coupling of component models.

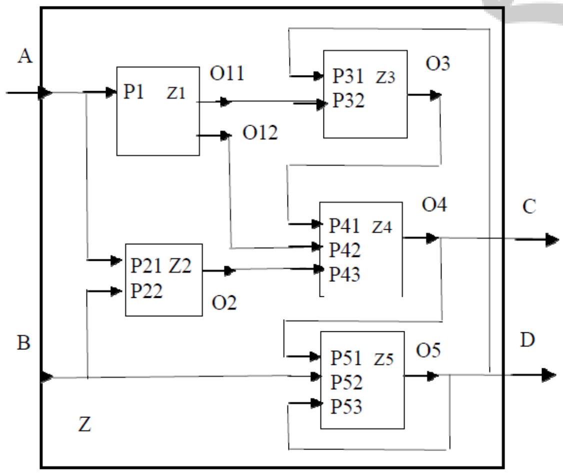

Figure 1: A coupled model Z (adopted from Ören, 2014).

Figure 2 (also from Ören, 2014) represents a template for model coupling. It consists of four parts: (1) Externals, i.e., coupled model's (or resultant model's) list of external inputs and outputs; (2) component models where a list of names of the component models to be coupled is given; (3) external coupling; and (4) internal coupling. Details of the coupling specification of Z, given in Figure 1 was covered in (Ören, 2014).

Coupled Model model-identifier
Externals -- input and output variables of the coupled model
Inputs -- list of external inputs
Outputs -- list of external outputs
End Externals

Component Models
-- List of names of component models
End Component Models

External Coupling
Inputs
-- equivalencing external inputs to internal inputs
-- for every external input specify
-- to which input of which component model(s) it is connected to
End Inputs

Outputs
-- equivalencing external outputs to internal outputs
-- for every external output specify
-- to which output of which component model it
is connected to
End Outputs
End External Coupling

Internal Coupling
-- for every component model
-- for every input variable (which is not connected to
an external input) specify
-- from which output variable of which component model the values are provided
End Internal Coupling
End Coupled Model model-identifier

Figure 2: Template for model coupling (adopted from Ören, 2014).

3 ADVANCED INPUT CONCEPTS

To be able to explore different types of input/output relationships of (atomic as well as already coupled component models, it is imperative to consider all kinds of inputs. In an article, Ören (2001a) dichotomized inputs as exogenous inputs (i.e., externally generated inputs) and endogenous inputs (i.e., internally generated inputs) and elaborated on each category. Some other publications on types of inputs are (Ören and Yilmaz, 2004; and Yilmaz and Ören, 2009). An updated version of the classification of the types of inputs is given in Tables 1 and 2. Table 1 summarizes externally generated inputs or exogenous inputs. As shown in Table 1, *perceived inputs* are generated outside of a system; however, the system needs to actively discern (or recognize) them.

Table 1: Types of exogenous (externally generated) inputs (Adopted from Ören and Yilmaz, 2009).

Exogenous Inputs	
Mode	**Type**
Imposed input (Passive acceptance of exogenous input)	**Access** to input - Direct input, coupling, argument passing, knowledge in a common area (blackboard), message passing, broadcasting (to all, to a fixed or varying group, to an entity) **Nature** of input - **Information** Data, facts, events, goals - **Sensation** (Converted sensory data (Table 3) from analog to digital – single or multi sensor – sensor fusion)
Perceived input (Active perception of exogenous input)	**Perception process** includes Noticing, recognition, decoding, selection (filtering), regulation **Nature** of input - **Interpreted sensory input** data (Table 3) and selected events - **Infochemicals** (Table 4) (chemical messages/chemical messengers for chemical communication) --sources: ---animate ---inanimate - **Infotraces** (traces of information transactions among: --interconnected infohabitants of ---Internet of things ---Users of media and search engines

Table 2 represents internally generated inputs or endogenous inputs. There are two categories of internally generated inputs: intropection, i.e., perception of internal knowledge (or realization of lack of some knowledge) and anticipated inputs. Types of sensations mentioned in Table 1 are elaborated on in Table 3.

Table 2: Types of endogenous (internally generated) inputs (Adopted from Ören and Yilmaz, 2009).

Endogenous Input	
Mode	**Type**
Perceived endogenous **input**	**Introspection** **Perceived** (cogitated) internal facts, events; or realization of lack of them
Anticipated / deliberated input	**Anticipation** **Anticipated facts** and/or **events** (behaviorally anticipatory systems) **Deliberation** **Deliberation** of past facts and/or events (deliberative systems) **Generation** **Generation** of goals, questions and hypotheses by: - Expectation-driven reasoning (Forward reasoning, or (Bottom up reasoning, or (Data-driven reasoning) - Model-driven reasoning

Table 3: Types of sensations (Adopted from Ören and Yilmaz, 2009).

Type of stimulus	**Type of perception**
light	- **vision** (visual perception): visible light vision, ultraviolet vision, infrared vision
sound	- **hearing** (auditory sensing): audible / infrasonic / ultrasonic sound (medical ultrasonography, fathometry)
chemical	- (**gas** sensing / detection): smell (smoke / CO2 / humidity sensor) - (**solid**, **fluid** sensing): taste, microanalysis
heat	- **heat** sensing
magnetism	- **magnetism** sensing: geomagnetism / thermo-magnetism sensing, electrical field sensing
touch	- sensing **surface characteristics**
motion	- **acceleration** sensing
vibration	- **vibration** sensing: seismic sensor

Chemical signals, or infochemicals are especially important in plants and animals (and even in inanimate entities) to assure several types of chemical communications. Table 4 categorizes some chemical signals (infochemicals or chemical messages / chemical messengers for chemical communication).

Table 4: Types of infochemicals for chemical communication.

<table>
<tr><td colspan="6">Infochemicals
(Chemical messengers for chemical communication)</td></tr>
<tr><td rowspan="4">Nature</td><td rowspan="3">Animate</td><td colspan="4">Hormones (Interactions are within a living organism between different organs or tissues)</td></tr>
<tr><td rowspan="3">Semio-chem-icals</td><td rowspan="2">Interactions are:</td><td>Intra-specific (same species)</td><td>Pheromones
(In early literature Echtohormones)</td></tr>
<tr><td>Inter-specific (different species)</td><td>Allelochemics (allomones, antimones, kairomones, synomones)</td></tr>
<tr><td>Inani-mate</td><td colspan="3">Apneumones</td></tr>
</table>

Infochemicals are chemical messages generated by animate or inanimate beings to influence the physiology or behavior of part of self, same or different species. They are very interesting, challenging, and pragmatically important. Especially, in biologically-inspired computing, they are very important and inspiring.

"Hormones are chemical messengers that are secreted directly into the blood, which carries them to organs and tissues of the body to exert their functions. There are many types of hormones that act on different aspects of bodily functions and processes. Some of these include: development and growth, metabolism of food items, sexual function and reproductive growth and health, cognitive function and mood, and maintenance of body temperature and thirst" (News-medical). In modeling physiological systems, functional coupling of the components organs can be expressed as time varying couplings.

Semiochemicals are chemicals emitted by an organism to influence the physiology or behavior of an organism of the same or a different species. They include pheromones and allelochemics. Applications of semiochemicals include insect pest control with limited or no contamination of environment. Some characteristics of semiochemicals are categorized in Table 5.

Pheromones are intraspecific behavior altering chemical agents. Based on their functions, there are: aggregation pheromones, alarm pheromones, caste-regulating pheromones, releaser pheromones, sex pheromones, and trail marking pheromones. *Allelochemics* are chemical messengers "produced by a living organism that exerts a detrimental physiological effect on individuals of another species when released into the environment" (OD).

Apneumones are chemicals "released by a non-living substance that is beneficial to the receiver" (Capinera, 2008, p. 230).

Table 5: Types of some allelochemics, based on their affection characteristics (Adopted from Barrows (2011, p. 102).

Signal to the benefit of		**receiver**	
		yes	no
sender	yes	*Synomones* (e.g., floral sent, pollinator)	*Allomones* (defence secretion, repellant; e.g., venom of snake/person)
	no	*Kairomones* (e.g., a parasite seeking a host)	*Antimones* (e.g., chemicals of a pathogene/host)

4 SYNERGY OF AGENTS AND SIMULATION

Most often, simulation of agent systems or simulation with agent-based models is considered. However, to see and get the full benefits, synergy of simulation and agents which is called Agent-Directed Simulation (ADS) is very important (Yilmaz, Ören, 2009). As shown in Table 6, synergy of simulation and agents consists of contributions of simulation for agents and contributions of agents for simulation.

Table 6: Types of agent-directed simulation.

<table>
<tr><td colspan="3"></td><td>Types of simulation</td></tr>
<tr><td rowspan="3">Synergy of simulation and agents
Agent-directed simulation (ADS)</td><td colspan="2">Contributions of simulation to agents</td><td>Agent simulation
- Simulation of agent systems or simulation with agent-based models.</td></tr>
<tr><td rowspan="2">Contributions of agents to simulation</td><td>Agents as support facilities</td><td>Agent-supported simulation
- Agent support for user/system interfaces
- Agents to enhance cognitive capabilities of modeling and simulation systems.</td></tr>
<tr><td>Agents as monitoring facilities</td><td>Agent-monitored simulation
- Includes model behavior generation.
- Agent-monitored coupling.</td></tr>
</table>

Simulation for agents (short form for ‘‘contributions of simulation to agents’’) is called agent simulation. Most common type of agent simulation is simulation of agent systems (or simulation of any system modeled by software agents or agent-based models). Agent simulation is also called ‘‘agent-based simulation’’ by those who do not take into account contributions of agents to simulation. Already many applications of agent simulation exist in engineering, human, and social dynamics, civilian as well as military applications. Sometimes the term “multi-agent” systems is also used.

Contributions of agents for simulation consist of two categories of possibilities: (1) use of agents as a support facility to enable computer assistance in problem solving and/or enhancing cognitive capabilities of simulation systems and (2) use of agents for simulation run-time activities.

As support facility, agents can support front-end user/system interface functions, such as problem specification or back-end user-system interface functions, such as data compression, explanation, problem and/or solution documentation, and solution selection. Agents can also enhance cognitive capabilities of modeling and simulation systems by providing understanding and multi-understanding abilities.

Use of agents for **simulation run-time activities** includes model behavior generation as well as other activities such as agent-monitored model update and agent-monitored coupling.

While dynamic composability, interoperation, and run-time extensibility in agent simulation is highly sought, contemporary coupling solutions often lack mechanisms for (dynamic) selection and assembly, as well as meaningful run-time interoperation among agents. In particular, they are limited in dealing with (1) dynamically evolving content (i.e., data, model) needs of existing federated agent applications and (2) run-time inclusion of new agents into a federated system with their own encoding standards and behavioral constraints. Besides, existing interoperation strategies are not transparent to the actual simulation infrastructure. Agent-monitored simulation also covers *agent-monitored coupling* where one or more agents examine interaction protocol between multiple agents to facilitate mediation, brokering, and matchmaking services (Yilmaz and Paspuletti, 2005).

Agents can provide various functions while monitoring and analyzing the coupling between agents. *Administration* is the process of managing the information exchange needs that exist between agents. Administration involves the overall information management process for the agent architecture. Location, discovery, and retrieval of content are critical components of administration. *Management* involves identifying, clarifying, defining and standardizing the meaning of content. *Alignment* ensures that the data to be exchanged exist in the participating agents as an information entity or that the necessary information can be derived from the available services published by the agents. *Transformation* is the technical process of aggregation and/or disaggregation of the information entities of the embedding systems to match the information exchange requirements.

5 AWARENESS-BASED COUPLINGS

Several types of cognitive input-output relationships are possible for intelligent agents. The input-output relations in the cognitive space include *perception-based couplings*, *introspection-based couplings,* and *anticipation-based* (Ören and Yilmaz, 2012) *couplings*. In general they can be categorized as *awareness-based couplings*.

Introspection-based coupling is part of self-awareness of agents. The awareness-based couplings will further be enriched by some other advanced concepts such as *variable couplings* (including time-varying couplings) and *nested couplings* as clarified by Ören (1971, 2014). These concepts lead to *context-sensitive coupling*.

To characterize soft coupling in the conceptual and physical spaces, we propose mechanisms that serve as filters to selectively allow agents to indirectly interact with others via the physical and conceptual space. In Tables 1-4, the input concept is extended with the signalling construct to facilitate agents to communicate with each other through infochemicals induced into the environment. Diffusion, aggregation, and evaporation of signals will enable time-varying coupling fields that emerge as agents interact in the physical and conceptual space. Similar to infochemicals, information traces can be used in information systems.

5.1 Context-mediated Perception

Chemical communication and coordination provide apt metaphors for devising advanced *perception-based coupling* strategies between agents. Dicke and Sabelis (1989) clarified infochemical terminology. A recent and more comprehensive clarification is given by Barrows (2011).

An *infochemic* is a chemical that conveys information between two interacting entities, triggering in the receiver a behavioural or physiological response that is adaptive to either one of the interacting agents or to both (Dicke and Sabelis, 1989).

A *pheromone* provides a *context-mediated coupling* mechanism by facilitating interaction between organisms of the *same species*. The interaction benefits the organism that originates the pheromone, to the receiver, or to both.
On the other hand, *allelochemics* enable interaction between two entities belonging to *different species* (Table 4). Allelochemics are divided into *synomones, allomones*, *kairomones*, and *antimones*.

In the case of *synomones*, the chemical released by the source organism results in behavior that is adaptively favorable to both the source (sender) and the receiver organisms. The pollination process serves as a good example that benefits both the plants and the insects. Allomone is a chemical that is pertinent to an organism such that when it contacts with an individual of another organisms, it evokes in the receiver a behaviour that is favorable to the originating organism. For instance, some emit toxins to deter herbivores to keep them away. A *kairomone* is a chemical that is pertinent to the source organism and that when it contacts with a second organisms, it triggers behavior in the target organism that is adaptively favorable to it, but not to the source organism. The release of chemical cues that attract predators is an example for kairomone. *Antimone* is a chemical substance which may be detrimental to the host of if its emitter. Barrows (2011) provides a wealth of information about allelochemics and pheromones.

Using the above metaphors, environment-mediated, indirect, and perception-based couplings can be defined in terms of their function in the interactions between agents. Among such *functional couplings* are alarm pheromones, aggregation and spacing pheromones, and diffusion (gossip) pheromones. The perception of a pheromone may trigger (releaser effect) a reactive in motion by the first perception (primer effect). Similarly, allelochemics can be used as a metaphor to define coupling functions such as enemy-avoidance and foraging kairomones. Tuning various properties of the infochemical-inspired signals can moderate coupling mechanisms between agents. The regulation can include volatility of the signals, stability in the context (environment), and rate of diffusion.

The benefits of *perception-based couplings* based on such context-mediated signals include their (1) effectiveness in the absence of direct coupling between agents that have different interfaces, or the presence of large number of diverse agents with coupling needs, (2) ability to provide time-coded signals and hence generating temporal effects, (3) capability to remain in an environment for an extended period of time, and (4) ability to avoid close proximity between coupled agents.

5.2 Deliberation-based Coupling

Agents with internal models of the environment as well of as peer agents can use deliberative mechanisms to perceive the intention of other agents and/or interpret their behavior. Interaction decisions are made selectively based on the goals, tasks, and activities that cohere together to achieve the desired high-level objectives. Agents use the current state and perceptions to deliberate and generate awareness models prior to initiating interaction decisions.

Deliberation-based couplings may also be important in simulation with holonic agents. Holonic agent simulation or holon simulation, in short, is an important type of agent simulation where agents represent holons. “Holonic systems are excellent candidates to conceive, model, control, and manage dynamically organizing cooperative systems” (Ören, 2001b). An important type of cooperation is co-opetition, i.e., limited cooperation of otherwise competitive entities. “A holonic system is composed of autonomous entities (called holons) that can deliberately reduce their autonomy, when need arise, to collectively achieve a goal. A holonic agent is a multi-agent system where each agent (called a holon) acts with deliberately reduced autonomy to assure harmony in its cooperation in order to collectively achieve a common goal” (Ören, 2001b).

5.3 Introspection and Anticipation-based Coupling

Agents with internal models of themselves (or a self-observing module) can interpret their own knowledge processing activities as well as perceive internal facts, events; or realization of lack of them. Hence, these internally generated knowledge can be used in some couplings as inputs. Relevant part of the coupling would then be *introspection-based coupling.* Ören and Yilmaz (2004) elaborated on behavioral anticipation in agent simulation. Knowledge generated by a behaviorally anticipatory entity can be an input to another relevant entity. The associated coupling is then an *anticipation-based coupling*.

6 SIMULATION/REAL-SYSTEM COUPLING

Table 7 represents possibilities for the relationships of the operations of the simulation and the real system. Most often, operations of simulation and real world system are not connected. This type of simulation is called standalone simulation. However, there are two cases where operations of simulation system and the real world can be closely related. This is the case of integrated simulation where simulation model can receive input directly from the real system. In this case one can consider simulation/real-world coupling.

Simulation model and real-world can be coupled for two reasons: To enrich or to support real system's operation. As clarified in Table 6, when simulation/real-world coupling is done to **enrich** real system's operation, the system of interest and the simulation program operate simultaneously. Two possible uses are: (1) online diagnostics (or simulation-based diagnostics) and (2) simulation-based augmented/enhanced reality operation (for training to gain/enhance motor skills and related decision making skills).

When simulation/real-world coupling is done to **support** real system's operation, the system of interest and the simulation program operate alternately to provide predictive displays. These parallel experiments while system is running would permit to use simulation to decide whether or not some or all decision variables should be changed.

Such couplings are especially useful for systems characterized by non-linear interactions among diverse agents that exhibit emergent behavior, which may be very different from what the initial conditions of these systems would suggest. Traditional simulation techniques that rely on accurate knowledge of these conditions typically fail in these cases. The Symbiotic Adaptive Multisimulation (SAMS) strategy (Mitchell and Yilmaz, 2009; Yilmaz and Mitchell, 2009) enables robust decision making in real-time for these types of problems. Rather than relying on a single authoritative model, SAMS explores an ensemble of plausible models, which are individually flawed but collectively provide more insight than would be possible otherwise.

Table 7: Types of simulation with respect to the connectivity (or coupling) of operations of simulation and real system (Adopted from Ören, 2009, p. 10).

Type of connectivity			**Type of simulation**
Operations of the simulation and the real system are	not connected		Standalone simulation
	interwoven (integrated simulation)	To ***enrich*** real system's operation	(The system of interest and the simulation program operate simultaneously) - online diagnostics (or simulation-based diagnostics) - simulation-based augmented/enhanced reality operation (for training to gain/enhance motor skills and related decision making skills)
		To ***support*** real system's operation	(The system of interest and the simulation program operate alternately to provide predictive displays) - parallel experiments while system is running

The insights derived from the model ensemble are then used to improve the performance of the coupled system under study. Likewise, as the system behavior unfolds, observations of emerging conditions can be used to improve exploration of the model ensemble. In essence, a useful co-evolution between the physical system and SAMS occurs. Self-simulation via SAMS provides a framework to generate anticipatory effects to explore system behavior. Through simulation/real-world coupling, a self-simulating system maintains accurate and consistent models of itself and the environment.

7 CONCLUSIONS AND FUTURE WORK

The concepts discussed in this article may enrich agent-based modeling and may also be inspirational for advanced coupling in simulation in general and in agent-directed simulation in particular. We are planning two courses of action:

(1) The generalization of the multi-model concept (Yilmaz and Ören, 2005) to multi-model agents. Afterwards their couplings will be elaborated on.

(2) Implementation of some of the advanced coupling concepts, especially awareness-based coupling concept for agents with emotion

understanding abilities for emotional intelligence simulation.

This article –with its 90+ types of model couplings– may also be a rich reference for modeling and simulation body of knowledge.

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APPENDIX

Terms denoting types of model couplings (over 90 types)

--A--

Affective coupling

Agent coupling

Agent-aided coupling

Agent-controlled coupling

Agent-monitored coupling

Allelochemic coupling

Allomone coupling

Anticipation-based coupling
Antimone coupling
Awareness-based coupling
--B--
Basic coupling
Broadcasted coupling
--C--
Cascade coupling
Cognitive coupling
Common coupling
Computer-aided coupling
Conjunctive coupling
Content coupling
Context-insensitive coupling
Context-mediated coupling
Control coupling
Conventional coupling
Coupling
Coupling of variable component model
Coupling with variable connection
--D--
Data coupling
Data-structured coupling
Decoupling
Deliberation-based coupling
DEVS coupling
Direct coupling
Disjunctive coupling
DNA-based coupling
Dynamic coupling
Dynamic federate-coupling
Dynamic model-coupling
--E--
Emotional coupling
Environment-mediated coupling
Essentially cascade coupling
External coupling
Feedback coupling
Functional coupling
--G--
Generalization coupling
GEST coupling
Graphic coupling
--H--
Hard coupling
Hierarchical coupling
Holonic agent coupling
--I--
Indirect coupling
Infochemical coupling
Informational coupling
Input/output coupling
Intermodular coupling
Internal coupling
Introspection-based coupling
--K--
Kairomone coupling
--L--
Limiting coupling
Logical coupling
Loose coupling
Loose temporal coupling
Low coupling
--M--
Miscoupling
Mixed coupling
Model coupling
Model/real-system coupling
Multi-level dynamic coupling
Multi-model agent coupling
Multi-model coupling
--N--
Nested coupling
Nonlinear coupling
Nonlinear statistical coupling
--P--
Perception-based coupling
Persistent coupling
Pheromone coupling
Pure feedback coupling
--R--
Resultant coupling
Runtime coupling
--S--
Sequential coupling
Semantic coupling
Singular coupling
Soft coupling
Specialization coupling

Subtype coupling
Supertype coupling
Stamp coupling
State coupling
State-dependent coupling
State-independent coupling
Static coupling
Structural coupling
Subclass coupling
Synomone coupling
System coupling
--T--
Targeted coupling
Temporal coupling
Tight coupling
Time-dependent coupling
Time-invariant coupling
Time-varying coupling
Topological coupling
--V--
Variable coupling
Volatile coupling