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Problems of Interoperability in Information Systems

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Four Challenges

- Enterprise Interoperability
- Knowledge-oriented Collaboration
- Web Technologies
- Interoperability Service Utility

Need dynamic connections

What is Underlying Logic?

- Not set theory
 - OK for closed local systems
 - But falls foul of Gödel as higher-order operations needed
 - Neither complete nor decidable outside FOPC
 - CWA is not realistic
 - But experimental verification is valuable
- Not pure category theory
 - Axiomatic
 - So also falls foul of Gödel

Process Logic

- Strong candidate
- Long pedigree
 - Heraclites
 - Whitehead
 - Category theory
 - Cartesian closed categories

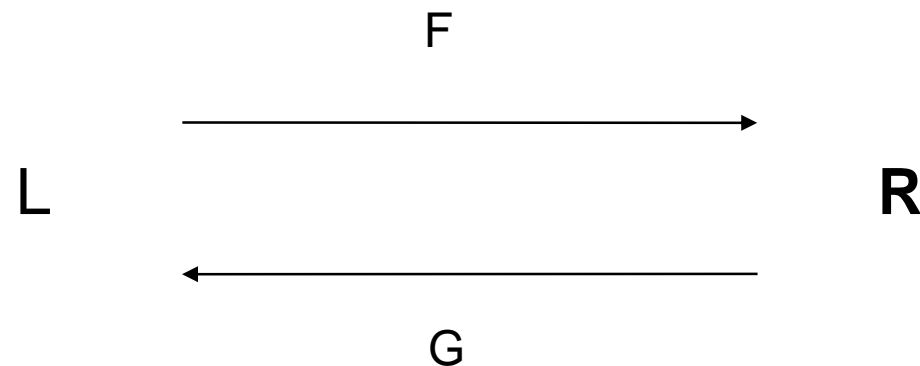
Uses of Category Theory

- Cartesian closed categories (CCC, naturality)
- Systems theory with Heyting logic (open systems)
- Topos (SoS)
- Monad (transaction logic, process)
- Adjointness (relationships)
- 2-categories (vertical + horizontal composition)
- Higher-order logic in CCC
 - Without axioms and reliance on number
 - Gödel free in connecting systems in our view
- For good practice, avoid categorification

Twin-track Approach

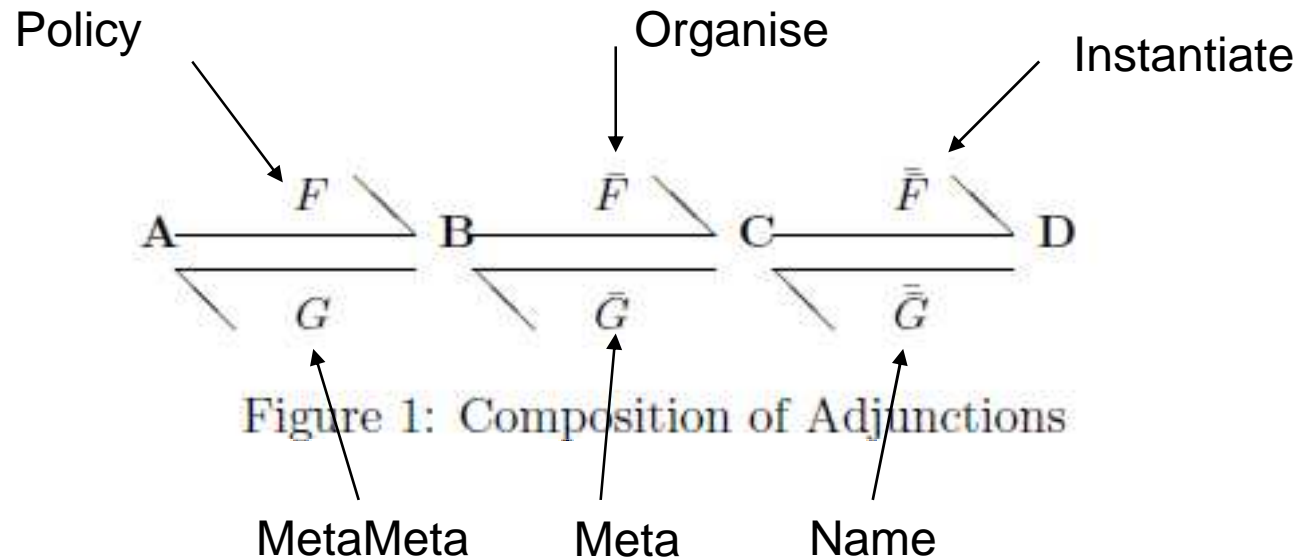
- Two subsystems
- 1. Data Structures and Rules
 - 3-level architecture
 - In terms of mappings $A \rightarrow B \rightarrow C \rightarrow D$
 - With dual $D \rightarrow C \rightarrow B \rightarrow A$
- 2. Behaviour
 - 3-level architecture
 - In terms of cycles $F: A \rightarrow B; G: B \rightarrow A$
 - GF 3 times
 - FG 3 times

Example of Adjointness



- If conditions hold, then we can write $F \dashv G$
- The adjunction is represented by a 4-tuple:
 - $\langle F, G, \eta, \varepsilon \rangle$
- η and ε are unit and counit respectively
- L, R are categories; F, G are functors

Data Structures and Rules



A is category for Concepts
B is category for Constructs
C is category for Schema
D is category for Data

Adjunctions compose naturally
 $F \dashv G$ is one of 6 adjunctions (if they hold)

Principles

- Have pairs of abstractions
- Each level is defined by level above
- Adjunctions permit relationships less than equivalence between the levels
- Having more than three levels of abstraction does not achieve greater precision
- Can be viewed as multi-level type subsystem

Six Possible Adjunctions

$$F \dashv G$$

$$\overline{F} \dashv \overline{G}$$

$$\overline{\overline{F}} \dashv \overline{\overline{G}}$$

$$\overline{F} F \dashv G \overline{G}$$

$$\overline{\overline{F}} \overline{F} \dashv \overline{G} \overline{\overline{G}}$$

$$\overline{\overline{F}} \overline{F} F \dashv G \overline{G} \overline{\overline{G}}$$

Adjunctions in More Detail

Simple Pairs

We can define these in more detail with their units and counits of adjunction as follows:

$$\langle F, G, \eta_a, \epsilon_b \rangle: \mathbf{A} \longrightarrow \mathbf{B} \quad (1)$$

η_a is the unit of adjunction $1_a \longrightarrow GFa$ and ϵ_b is the counit of adjunction $FGb \longrightarrow 1_b$

$$\langle \bar{F}, \bar{G}, \bar{\eta}_b, \bar{\epsilon}_c \rangle: \mathbf{B} \longrightarrow \mathbf{C} \quad (2)$$

$\bar{\eta}_b$ is the unit of adjunction $1_b \longrightarrow \bar{G}\bar{F}b$ and $\bar{\epsilon}_c$ is the counit of adjunction $\bar{F}\bar{G}c \longrightarrow 1_c$

$$\langle \bar{\bar{F}}, \bar{\bar{G}}, \bar{\bar{\eta}}_c, \bar{\bar{\epsilon}}_d \rangle: \mathbf{C} \longrightarrow \mathbf{D} \quad (3)$$

$\bar{\bar{\eta}}_c$ is the unit of adjunction $1_c \longrightarrow \bar{\bar{G}}\bar{\bar{F}}c$ and $\bar{\bar{\epsilon}}_d$ is the counit of adjunction $\bar{\bar{F}}\bar{\bar{G}}d \longrightarrow 1_d$

Adjunctions in More Detail Doubles

$$\langle \bar{F}\bar{F}, G\bar{G}, G\bar{\eta}_a F \bullet \eta_a, \bar{\epsilon}_c \bullet \bar{F}\epsilon_c \bar{G} \rangle: A \longrightarrow C \quad (4)$$

$G\bar{\eta}_a F \bullet \eta_a$ is the unit of adjunction $1_a \longrightarrow G\bar{G}\bar{F}F a$ and $\bar{\epsilon}_c \bullet \bar{F}\epsilon_c \bar{G}$ is the counit of adjunction $\bar{F}F G\bar{G}c \longrightarrow 1_c$

The unit of adjunction is a composition of $\eta_a : 1_a \longrightarrow GFa$ with $G\bar{\eta}_a F : GFa \longrightarrow G\bar{G}\bar{F}F a$

The counit of adjunction is a composition of $\bar{F}\epsilon_c \bar{G} : \bar{F}F G\bar{G}c \longrightarrow \bar{F}\bar{G}c$ with $\bar{\epsilon}_c : \bar{F}\bar{G}c \longrightarrow 1_c$

We have retained the symbol \bullet indicating vertical composition as distinct from normal horizontal composition indicated by the symbol \circ [13].

$$\langle \bar{\bar{F}}\bar{\bar{F}}, \bar{\bar{G}}\bar{\bar{G}}, \bar{\bar{G}}\bar{\bar{\eta}}_b \bar{\bar{F}} \bullet \bar{\eta}_b, \bar{\bar{\epsilon}}_d \bullet \bar{\bar{F}}\bar{\bar{\epsilon}}_d \bar{\bar{G}} \rangle: B \longrightarrow D \quad (5)$$

$\bar{\bar{G}}\bar{\bar{\eta}}_b \bar{\bar{F}} \bullet \bar{\eta}_b$ is the unit of adjunction $1_b \longrightarrow \bar{\bar{G}}\bar{\bar{G}}\bar{\bar{F}}\bar{\bar{F}}B$ and $\bar{\bar{\epsilon}}_d \bullet \bar{\bar{F}}\bar{\bar{\epsilon}}_d \bar{\bar{G}}$ is the counit of adjunction $\bar{\bar{F}}\bar{\bar{F}}\bar{\bar{G}}\bar{\bar{G}}d \longrightarrow 1_d$

The unit of adjunction is a composition of $\bar{\eta}_b : 1_b \longrightarrow \bar{G}\bar{F}b$ with $\bar{\bar{G}}\bar{\bar{\eta}}_b \bar{\bar{F}} : \bar{G}\bar{F}b \longrightarrow \bar{\bar{G}}\bar{\bar{G}}\bar{\bar{F}}\bar{\bar{F}}b$

The counit of adjunction is a composition of $\bar{\bar{F}}\bar{\bar{\epsilon}}_d \bar{\bar{G}} : \bar{\bar{F}}\bar{\bar{F}}\bar{\bar{G}}\bar{\bar{G}}d \longrightarrow \bar{\bar{F}}\bar{\bar{G}}d$ with $\bar{\bar{\epsilon}}_d : \bar{\bar{F}}\bar{\bar{G}}d \longrightarrow 1_d$.

Adjunctions in More Detail Triples

$$\langle \bar{F}\bar{F}\bar{F}, \bar{G}\bar{G}\bar{G}, \bar{G}\bar{G}\bar{\eta}_a\bar{F}\bar{F} \bullet \bar{G}\bar{\eta}_a\bar{F} \bullet \eta_a, \bar{\epsilon}_d \bullet \bar{F}\bar{\epsilon}_d\bar{G} \bullet \bar{F}\bar{F}\bar{\epsilon}_d\bar{G}\bar{G} \rangle: \mathbf{A} \longrightarrow \mathbf{D} \quad (6)$$

The unit of adjunction is a composition of:

$$\eta_a : 1_a \longrightarrow GFa \text{ with } G\bar{\eta}_a\bar{F} : GFa \longrightarrow G\bar{G}\bar{F}\bar{F}a \text{ with } G\bar{G}\bar{\eta}_a\bar{F}\bar{F} : G\bar{G}\bar{F}\bar{F}a \longrightarrow G\bar{G}\bar{G}\bar{F}\bar{F}\bar{F}a$$

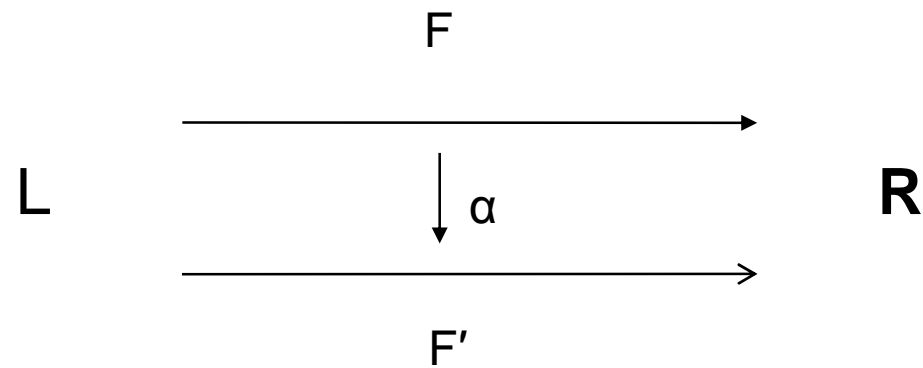
The counit of adjunction is a composition of:

$$\bar{F}\bar{F}\bar{\epsilon}_d\bar{G}\bar{G} : \bar{F}\bar{F}\bar{F}\bar{G}\bar{G}\bar{G}d \longrightarrow \bar{F}\bar{F}\bar{G}\bar{G}d \text{ with } \bar{F}\bar{\epsilon}_d\bar{G} : \bar{F}\bar{F}\bar{G}\bar{G}d \longrightarrow \bar{F}\bar{G}d \text{ with } \bar{\epsilon}_d : \bar{F}\bar{G}d \longrightarrow 1_d$$

Desired Properties

- If all adjunctions hold
 - Have clearly-defined multi-level type subsystem
- Can relate one subsystem to another by
 - Natural transformation
 - Maps between functors
- Provides interoperability between subsystems for
 - Data structures and rules

Natural Transformation



α is natural transformation comparing F and F'

Behaviour/Anticipation Monad/Comonad

- Define subsystem
 - Handle transactions
 - ACID properties
 - Atomicity, Consistency, Isolation, Durability
 - Have 3 cycles
 - 1. make changes
 - 2. review changes
 - 3. holistic check that all is well
 - Example with Bank ATM:
 - 1. debit account
 - 2. check funds available
 - 3. holistic check that all changes recorded safely

Monad

- Construction for transactions is the Monad
- Monad is a triple $\langle T, \eta, \mu \rangle$
 - T is an endofunctor (functor with same source and target)
 - e.g. $GF : A \rightarrow B \rightarrow A$
 - η is unit of adjunction e.g. $1_L \rightarrow GF(L)$
 - Compares initial value for object L with value for L after one cycle
 - μ is multiplication $T^2 \rightarrow T$
 - comparing result from 2nd cycle with 1st
 - e.g. $GFGF \rightarrow GF$
- Full details of definition involve T^3 (GFGFGF)

Comonad

- Monad gives left-hand-perspective (L)
- Comonad gives right-hand perspective (R)
- Comonad is a triple $\langle S, \varepsilon, \delta \rangle$
 - S is FG
 - e.g. $B \rightarrow A \rightarrow B$
 - ε is counit of adjunction e.g. $FG(R) \rightarrow 1_R$
 - δ is comultiplication $T \rightarrow T^2$
 - Anticipation – looking forward

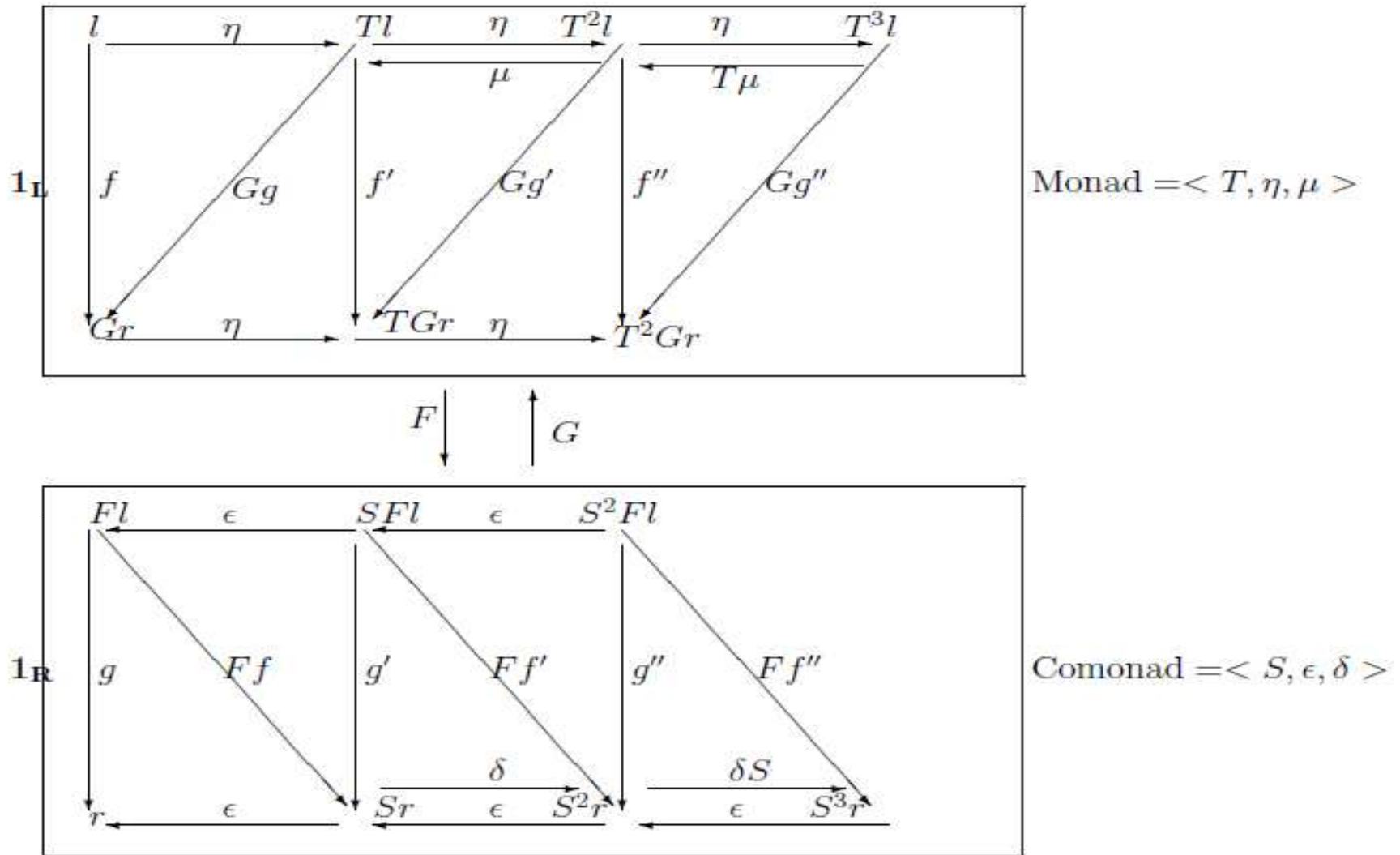


Figure 2: After three cycles $GFGFGF$ from left-hand category and three cycles $FGFGFG$ from right-hand category: η and δ map onto other than \perp , \top maps onto other than ϵ and μ

System Viewpoint for Interoperability

- Have a system formed from 2 subsystems
 - For data structures/rules
 - 3 levels of mapping as functors between categories
 - Each mapping represents a level-pair of abstractions
 - For behaviour
 - 3 cycles as a monad/comonad structure
- Interoperability
 - Comparing one system with another by natural transformations or higher-order categories
- Recent work on Security by PhD student Dimitris Sisiaridis with category theory produces the system unification

Possible Way Forward

- Not for everybody to learn category theory!
- Development of tool
 - Assist with interoperability
 - Based on process category theory
 - Graphical
 - Haskell is a candidate
 - Facilities include monads