# Ensuring Consistency between Classifiers and Classes

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# Our Challenge

- How can we keep non-code development artifacts synchronized with source code?
  - requirements and feature descriptions (Microsoft Word or text documents)
  - architecture descriptions (Viseo drawings, SVG or text documents)
  - design artifacts (UML documents as encoded by XML files)
  - specifications (structured English + pragmas)

# Current State of Affairs

- requirements are written by customers
- features are written by marketing
- analysis and design documents are written by “architects”
- specifications are written by programmers
- tests are written by Q/A and programmers

- **in general, there is no consistency check!**

# Our Solution: Refinement using Type-logical Grammars

# Refinement Big-Picture

Informal EBON

```
class_chart LOGICAL_CLOCK

explanation
  "A logical clock."
query
  "What is the current time for this clock?"
command
  "Advance the clock; update the clock's time."
constraint
  "The time must be non-negative.",
  "Must support concurrent use by multiple clients."
end
```

Formal EBON

```
indexing
  about:        "A logical clock.";
  title:        "TickTockClock";
  author:       "Joe Kiniry";
  copyright:    "Copyright (C) 2007 Joe Kiniry";
  organisation: "School of Computer Science and Informatics, UCD";
  date:         "January 2007";
  version:      "Revision: 11";

static_diagram
component
  deferred class LOGICAL_CLOCK

  feature
    my_time: INTEGER  -- The current time of this clock.

    -- What is the current time of this clock?
    deferred get_logical_time: INTEGER
      -- concurrency: CONCURRENT
      -- modifies: QUERY
      ensure
        Result = my_time;
      end

    deferred advance  -- Advance this clock's time.
      -- concurrency: GUARDED
      -- modifies: my_time
      ensure
        -- This clock's time has monotonically increased.
        old my_time < my_time;
      end

  invariant
    0 <= my_time;

  end -- class LOGICAL_CLOCK

end --component
```

JML

```
/**
 * A logical clock.
 * @title        "TickTockClock"
 * @date         "2007/01/23 18:00:49"
 * @author       "Fintan Fairmichael"
 * @organisation  "CSI School, UCD"
 * @copyright    "Copyright (C) 2007 UCD"
 * @version      "$ Revision: 1.7 $"
 */
public interface LogicalClock {
  // The current time of this clock.
  //@ public model instance \bigint _time;

  //@ public invariant 0 <= _time;

  /**
   * @return What is the current time of this clock?
   * @concurrency CONCURRENT
   */
  //@ ensures \result == _time;
  public /*@ pure @*/ long getLogicalTime();

  /**
   * Advance this clock's time.
   * @concurrency GUARDED
   */
  //@ assignable _time;
  //@ ensures \old(_time) < _time;
  //@ ensures (* _time has been increased. *);
  public void advance();
}
```

Java

```
/**
 * A logical clock implementation.
 * @author "Joseph Kiniry"
 */
public class LogicalClockImpl implements LogicalClock {
  /** The current logical time. */
  private long my_time = 0; //@ in _time;
  //@ private represents _time <- my_time;

  public long getLogicalTime() {
    return my_time;
  }

  public void advance() {
    my_time++;
  }
}
```

# Example Refinement

```
class_chart ALARM
explanation
  "An alarm."
query
  "Is this alarm on?"
command
  "Turn this alarm on.",
  "Turn this alarm off."
constraint
  "The alarm is either on or off."
end
```

```
indexing
  about: "An alarm.";
static_diagram
component
  deferred class ALARM
  feature
    deferred on  -- Turn this alarm on.
      ensure
        is_on();
      end
    deferred off  -- Turn this alarm off.
      ensure
        not is_on();
      end
    deferred is_on: BOOLEAN  -- Is this alarm on?
  invariant
    on xor off  -- The alarm is either on or off.
  end
end
```

```java
/**
 * An alarm that is either on or off.
 * ...
 */
public interface AlarmInterface {
  /** Turn this alarm on. */
  //@ ensures isOn();
  public void on();

  /** Turn this alarm off. */
  //@ ensures !isOn();
  public void off();

  /** @returns Is this alarm on? */
  public /*@ pure @*/ boolean isOn();
}
```

...

# Type-logical Semantics

- Bob Carpenter (while at CMU in early 90s)
  - *lexical semantics* characterizing the meaning of expressions
  - *compositional semantics* explains the meanings of arbitrarily complex linguistic expressions in terms of the meaning of their subexpressions and the manner in which they are combined

# Logical Foundations

- simple grammars in lambda-calculus and higher-order (modal) logic
  - simple sentences in English with argument and adjunct structure
- categorical grammar based upon type-theory and its associated logic
  - coordination, quantifier scope, anaphora, unbounded dependency constructions

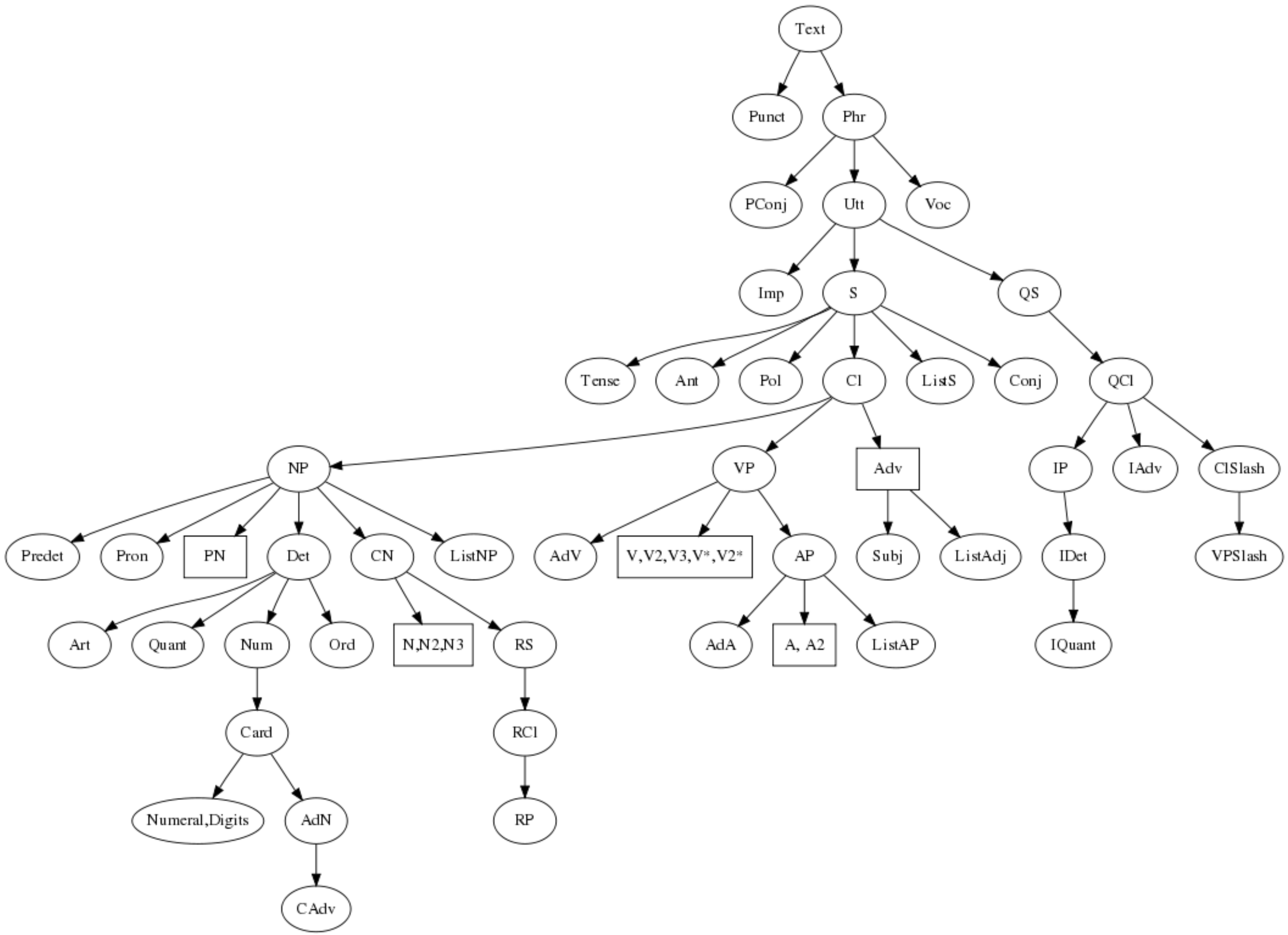
# The Grammatical Framework (GF)

- Aarne Ranta's group in Gothenburg, Sweden
- FLOSS special-purpose functional language and NLP framework for writing grammars
- interfaces with Haskell, Java, JavaScript, etc.
- encode categorical grammars a la Carpenter
- is a logical framework a la PVS/Coq/Isabelle
- has been used to translate: mathematical proofs into English, formal specifications into English, natural languages, etc.

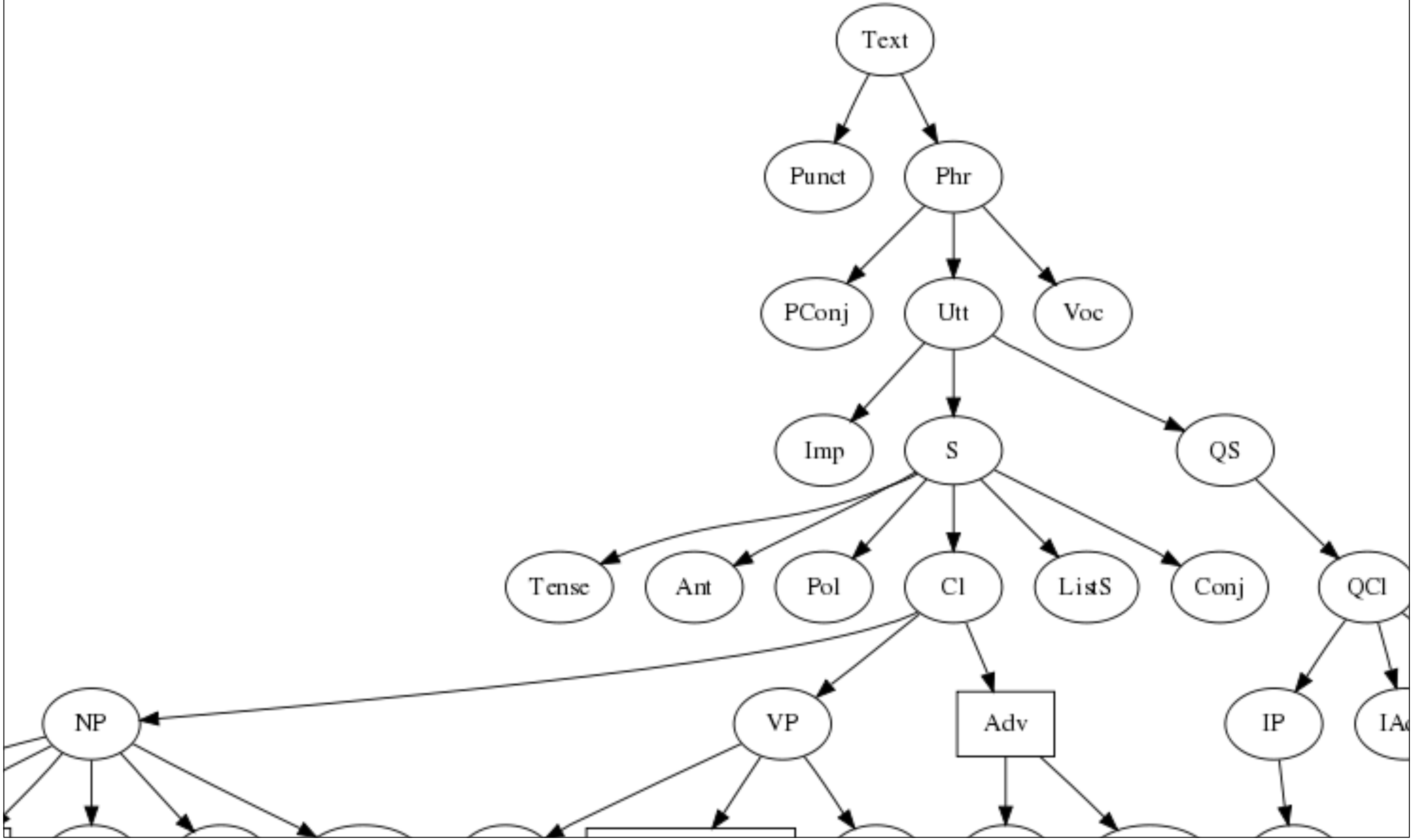
# GF Language Features

- static type checking
- higher-order functions
- dependent types
- pattern matching with data constructors and regular expressions
- module system with multiple inheritance and parameterized modules

# Categories in GF



# Categories in GF



# CFGs in GF

```
Pred. S ::= NP VP;
Compl. VP ::= V2 NP ;
John. NP ::= "John" ;
Mary. NP ::= "Mary" ;
Love. V2 ::= "loves" ;
```

**John loves Mary**

Returns the natural logarithm (base e) of a double value.

# Separating Abstract and Concrete Syntax

- each rule is converted to two **judgements**
  - *fun*, declaring a **syntactic function**
  - *lin*, giving its **linearization rule**

```
Pred. S ::= NP VP ===> fun Pred : NP -> VP -> S
                       lin Pred np vp = np ++ vp
```

# GF Grammars

- grammars are divided into two **modules**
  - **abstract** module (*cat* and *fun* judgements)
  - **concrete** module (*lincat* and *lin* judgements)

| **Judgement** | **Interpretation** |
|---|---|
| cat C | C is a category |
| fun f: T | f is a function of type T |
| lincat C = L | C has linearization type L |
| lin f xs = t | f xs has linearization t |

# Execution Strategy

- develop an abstract grammar for software engineering artifacts
  - categories for system, cluster, class, description, explanation, query, command, constraint, and other semantic properties
- create concrete grammars for each concrete syntax
  - restricted English found in documentation
  - EBON CFG
- *define type refinements between categorical types*

# Kind Theory

- paraconsistent, autoepistemic, categorical logic of reuse
- used to describe relationships between reusable artifacts and their instances
  - informal description $\hookleftarrow$ formal model-based specification $\hookleftarrow$ BISL $\hookleftarrow$ source $\hookleftarrow$ object code
  - informal EBON $\hookleftarrow$ formal EBON $\hookleftarrow$ JML $\hookleftarrow$ Java source code $\hookleftarrow$ Java bytecode

# Commuting Diagrams

if

- U is a part of V and
- V interprets to W

then

- U interprets to P
- P is a part of W
- an interpretation of “part of” exists

$$
\begin{tikzcd}[row sep=huge, column sep=huge]
U \arrow[r, "\subset_p"] \arrow[d, dashed, "\rightsquigarrow"'] \arrow[dr, phantom, "\rightsquigarrow\ \Downarrow"] & V \arrow[d, "\rightsquigarrow"] \\
P \arrow[r, dashed, "\subset_p"] & W
\end{tikzcd}
$$

# Feature Refinement

$$
\begin{tikzcd}
\text{(query) “Current time?”} \arrow[rr, "\subset_p"] \arrow[d, dashed, "\rightsquigarrow"'] & {} \arrow[d, dashed, "\rightsquigarrow"'] & \text{(BON informal class) LOGICAL\_CLOCK} \arrow[d, "\rightsquigarrow"] \\
\text{(feature) my\_time: INTEGER} \arrow[rr, dashed, "\subset_p"] \arrow[d, dashed, "\rightsquigarrow"'] & {} \arrow[d, dashed, "\rightsquigarrow"'] & \text{deferred BON class LOGICAL\_CLOCK} \arrow[d, "\rightsquigarrow"] \\
\text{(pure method) long getLogicalTime()} \arrow[rr, dashed, "\subset_p"] & {} & \text{Java interface LogicalClock}
\end{tikzcd}
$$

# In Action

```
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end
```

$\mathrm{ALARM} \triangleq$
$\mathrm{this} \rightarrow \mathrm{Expl} \otimes$
$\mathrm{on}: \mathrm{this} \rightarrow \mathrm{B} \otimes$
$\mathrm{turn\_on}: \mathrm{this} \rightarrow \mathrm{B} \rightarrow \mathrm{this} \otimes$
$\mathrm{turn\_off}: \mathrm{this} \rightarrow \mathrm{B} \rightarrow \mathrm{this}$

# The BON Tool Suite

- *BONc*: compiler-like framework for EBON (parser, type-checker, doc generation, etc.)
- *Beetlz*: refinement checker and generator between EBON and JML (fully round-trip)
- *BON Eclipse perspective* (integrates graphical and textual view of EBON)
- *GF-based refinement* (refinement checker and generator between informal and formal EBON)

# Next Steps

- mechanical formalization of refinement in HOL
- integration of type-logical grammar work
- verification of refinement implementation
- extended static checking for English
- integration with WordNet and OpenCyc
- semantic types via JML contracts

# Thanks

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