

# Modular Computational Effects

## A Comparison of Techniques and Approaches

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### 1. INFORMAL AG DESCRIPTION

An AG is a context-free grammar with attributes declared for each nonterminal. The attributes represent both input and output for computations ‘over’ the trees described by the grammar, and can be used for providing context-information or “simulating” effects. Input is provided by *inherited attributes* and output by *synthesised attributes*. When an attribute is both inherited and synthesised we call it a *chained attribute*. Computations are described by giving *semantic definitions* to attributes in terms of other attributes. Semantic definitions are essentially equation relating an attribute occurrence to an expression built from other attributes and functions/operators defined in some host language. It is the task of an *attribute evaluator* to traverse a syntax tree and evaluate the necessary attributes according to their semantic definitions, thus performing the described computations.

I will from now on talk specifically about UUAG, the Utrecht University Attribute Grammar formalism, which I think is the most expressive AG formalism available to functional programmers. This means, among other things, that I use the word datatype rather than nonterminal and constructor rather than production.

#### 1.1 Modular Specifications

An UUAG specification consists of three components:

1. Datatype definition
2. Attribute declaration, specific to a datatype
3. Semantic definitions, specific to a constructor

The datatypes are extensible in the sense that new constructors and attributes for that type can be given in isolation (although all constructors of a datatype are grouped together which Haskell code is generated).

The attributes declared for a nonterminal raise certain requirements to be fulfilled by the semantic definitions:

- An inherited attribute  $i_1$  declared for datatype  $X$  demands a definition for the attribute occurrence  $X_1.i_1$ , for each occurrence  $X_1$  of  $X$  as an argument to some constructor.
- A synthesised attribute  $s_1$  declared for datatype  $X$ , demands a definition for attribute occurrence  $\mathbf{lhs}.s_1$ , for each constructor of  $X$  ( $\mathbf{lhs}$  stands for left-hand side).

When a definition is missing, the UUAGC (UUAG compiler) generates definitions automatically when possible, relying on so called use- and copy-rules. As such, use- and copy-rules implicitly propagate the values of any unmentioned attributes. When we add a datatype or constructor (more syntax), we do not have to give definitions for attributes declared elsewhere. Similarly, when declaring new attributes (with the purpose of describing the semantics of some syntax) we do not have to worry about other bits of syntax that are not influenced by these attributes. To which extent the use/copy-rule mechanism enables *\*composing\** effects will be the target of our investigation.

The UUAGC generates a single semantic function for each production of a nonterminal, even if semantic definitions are spread across different code fragments or compilation units. As such, some form of fusion takes place automatically. The resulting semantic function may not terminate, if it contains a proper cycle. However, the UUAGC can be asked to perform compile-time scheduling to avoid nontermination, effectively “unfusing” where necessary.

#### 1.2 Higher-Order AGs

UUAG supports higher-order Attribute Grammars. The main idea is that the values of attributes may be syntax trees themselves, and that we may evaluate these syntax trees when necessary. We may extend a syntax tree by declaring, as part of the semantic definitions of a constructor, a new argument to that constructor (a new nonterminal occurrence, in context-free grammar terms). This additional argument will be instantiated, at runtime, by the value of some attribute (as specified in the semantic definitions). This extension greatly enhances the expressiveness of UUAG, as arbitrary recursive computations can now be defined.

A common pattern in domain of programming language semantics is to mark a certain argument to a constructor as being *\*terminal\**, ensuring that it will not be evaluated. (A copy of) The argument may then be ‘transported’ to another location in the syntax tree, where it is evaluated instead. This resembles continuation passing. As I showed at the Haskell eXchange, this feature can be used to handle cut/cutfail.