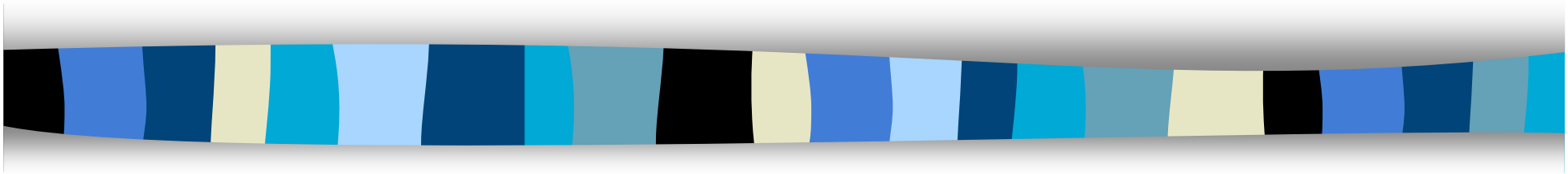
Which formal languages for natural languages?



Christian Retoré

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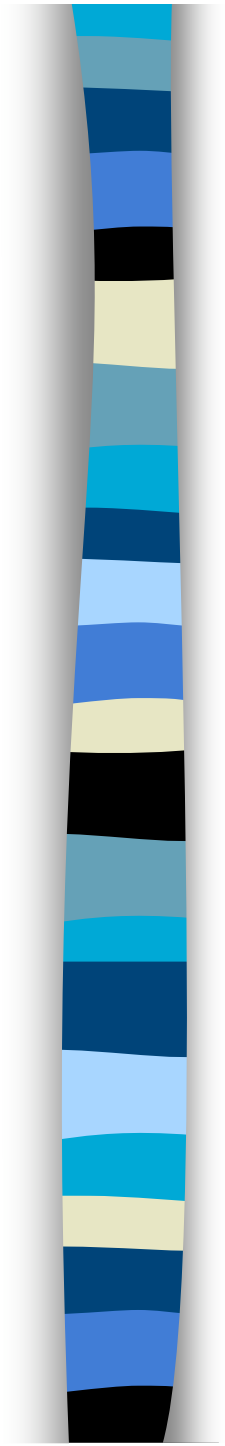
Bon anniversaire, Gérard!

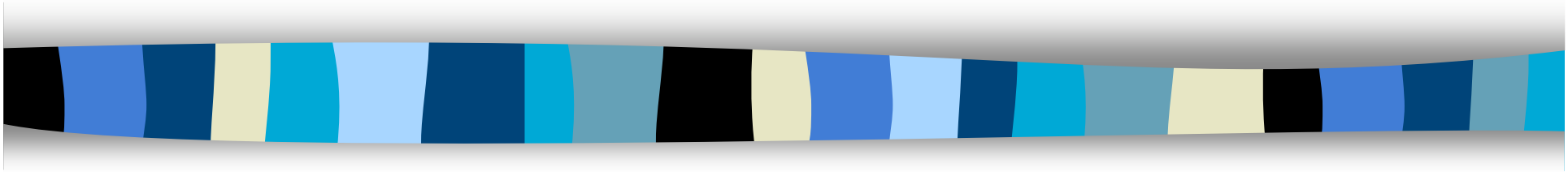
- 1988 *« L'intelligence artificielle ne pallie pas la bêtise naturelle. » If you cannot proceed the exercice, you can think about the sentence's meaning.* Lecture notes on logic, prolog exercice found in Paris 7 maths department.
- 2000 My best student ever (ex-aequo with Géraud Sénizergues later) at ESSLLI 2000 in rainy Birmingham on *The logic of categorial grammars*
- 2003 Signes team and rainy experience in *Plume la Poule*, leading to the unfortunate « Gérard Huet, le linguiste des robots »(Le Point, Edition Aquitaine)



Survey with something new

- Formal syntax of natural language
- Natural language syntax with strings
- State of the art and discussion
- Tree languages for natural language
- The place of Edward Stabler's minimalist grammars in the hierarchy
  (very recent joint work with Gregory Kobele and Sylvain Salvati)

Back to the origins of computational linguistics



Which formal languages
for natural language syntax?
(first strings, then trees)

Two traditions

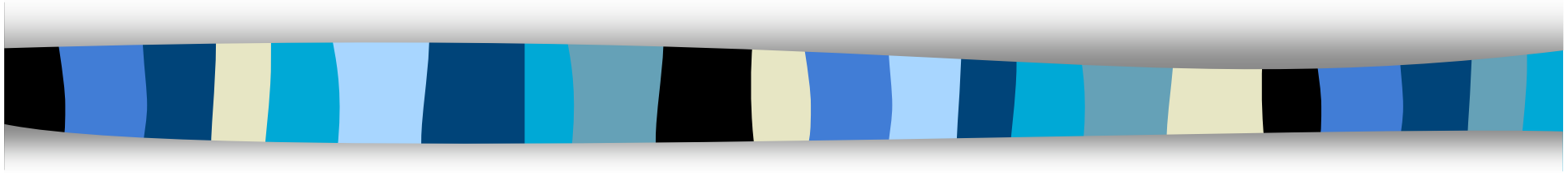
1. Logic and grammar
   - Denis from Thrax (Alexandria, Byzance)
   - Scholastics
   - Frege, Montague, Lambek
2. Grammar and computation
   - Panini
   - Chomsky, Schutzenberger

Two traditions

1. Logic and grammar
   ++ connexion to semantics
   + learning
   - - efficiency, complexity
2. Grammar and computation
   ++ Complexity, (abstract) machines
   - Learning
   - - Connexion to semantics

Me: 1 visiting 2

Has there been a “Chomskian revolution” in linguistics? (Newmeyer 1986)



Probably,
but definitely one in computer science

(formal languages are everywhere)

From behaviorism to generative grammar Chomsky 1955

- Language ≠ corpus
  He believes that (longuest sentence)
- Language: set of unconscious rules
  evidence: learning overgeneralisation.
  Against learning by imitation.
  Why the child holded the baby rabbit
- Competence (rules) ≠ performance
  The wheat {that the rat [that the cat (that the dog chased) killed] ate} was poisonous.

Two principles

1. Fast (polynomial?) analysis
   Grammaticality is decided quickly by speakers
2. Learnable under some conditions
   - Knowing argument structure and root meaning
   - With interaction
   - With prosody
   - With positive examples only
   - Not that much positive examples
   - By iterated restrictions of the language

Formal grammars

- T terminals, N non terminals
- Rules W –> W’ (W: at least one N)

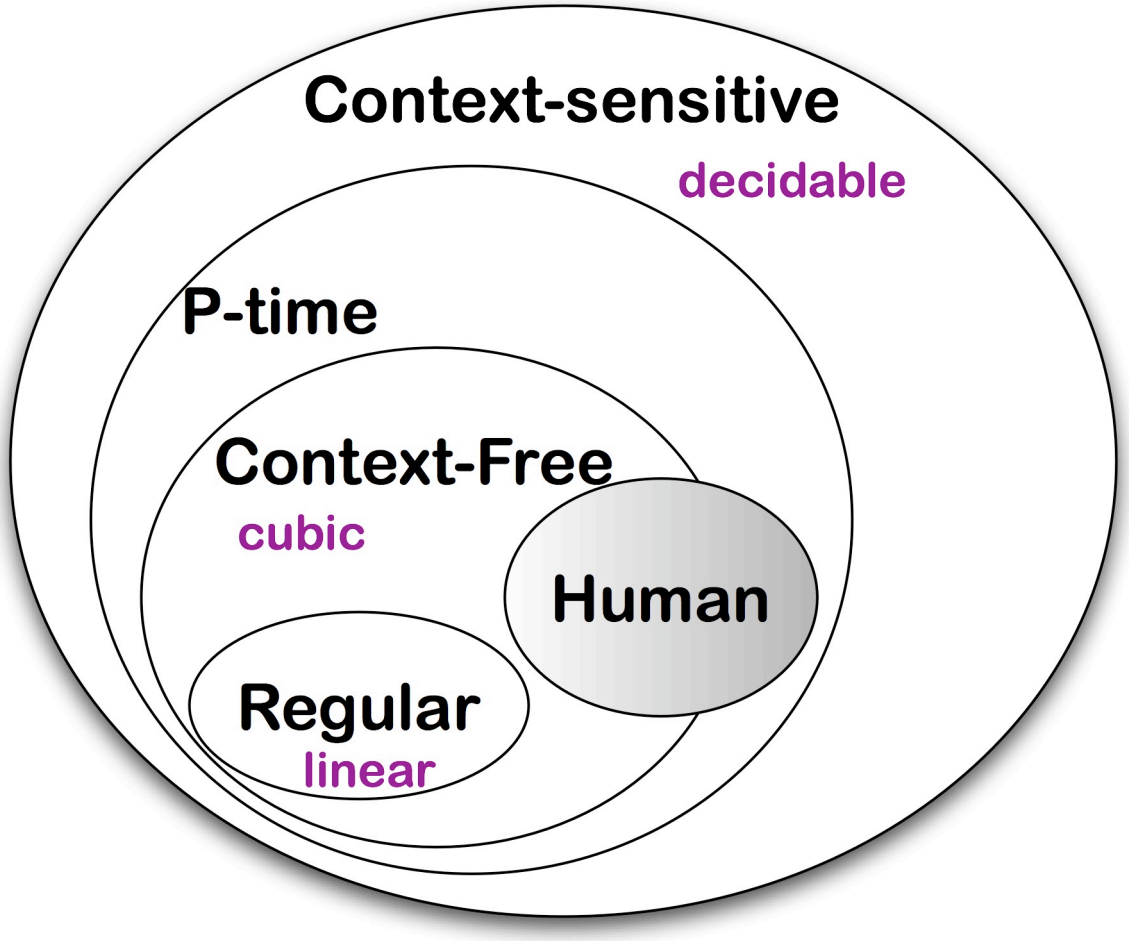
={

  - W=W1 Z W2 and W’= W1 W’’ W2 context sensitive
  - |W’|≥|W| length increasing
  - |W|=1 context-free
  - |W|=1 and W’=mZ regular

Which string languages?

- Center-embedded relatives
  Pierre (que Pierre)^n connaît^n dort.
  at least context-free.
- Dutch (Swiss-German) completives
  …dat ik$_1$ Henk$_2$ haar$_3$ de nijlpaarden$_3$
  zag$_1$ helpen$_2$ voeren$_3$
  … that I$_1$ see$_1$ Henk$_2$ help$_2$ her$_3$ to feed$_3$
  the hippopotamuses

The current hypothesis on human string languages



Challenged from time to time:

Michaelis & Kracht 96 old Georgian is not semi-linear

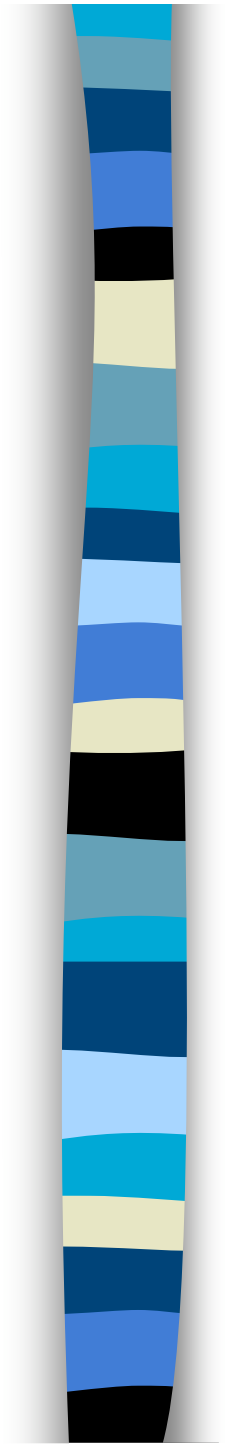
Kobele 06 Yoruba involves unbounded copying

Generative grammar

- Universal grammar / parameters
  explaining the acquisition paradox
- Movement / comparison between sentences
  Which book that Chomsky wrote did he like?
  He likes three books that Chomsky wrote.
- Syntax/semantics
  quantifiers
  possible impossible coreferences
  (affirmative: he and Chomsky non coreferent)

Mildly context sensitive languages

- First notion:
  - Tree Adjoing Grammars 1975 “come back” late 80’s
  - Combinatorial Categorial Grammars Steedman 1990
- A larger one:
  - Multi-Component-TAG Weir 1988
  - Minimalist grammars Stabler 1996
  - LCFRS Vijay-Shankar,Weir, Joshi 1987
    MCFG Seki, Matsumura, Fujii, Kasimi 1991
- The largest suitable class = P-time
  Literal Movement Grammars Groenink 1997
  (simple or indexed, as they are weakly equivalent)
  Range Concatenation Grammars Boullier 1999

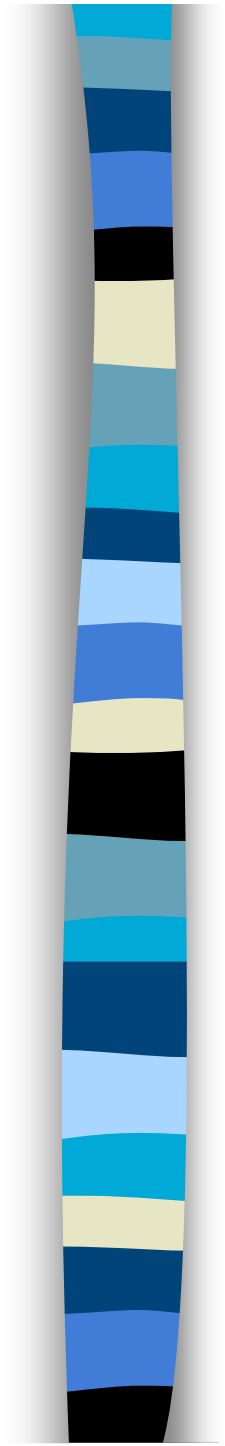


Discussion: complexity

- Recursion limited to two (or say five)
  - Computer = finite state automaton??
  - Speakers (with extra processing time) accept nested sentences
  - Rules are stated like this by speakers, books, …
  - Economy of the description

Discussion: word order

- Models of strict word orders, what about more free word order (e.g. with rich morphology, Latin, Russian, Sanskrit)
  - Standard answer: there is a canonical order from which other are derived and it induces semantic nuances
  - A hidden answer: it is much simpler to work with total orders then with partial orders!!



Discussion: acquisition

- Acquisition condition left out…
  but very important
  - for understanding human language faculty
  - for building large grammars from corpora.
- Exception: categorial grammars can be learnt:
  - lexicalized
  - structured types -> unification

Discussion: practical state of the art

- Richard Moot MMCG: extraction, parsing
  - NWO Dutch Spoken Corpus (spontaneous conversation, annotated transcript)
    - 1.002.098 word occurrences
    - 114.801 phrases (7,6 words per sentence)
    - 44.306 different word forms
  - Multi-Modal Categorial Grammar, acquired from the corpus (average 100 trees per word!)
  - Supertagging (n-most likely sequences of trees corresponding to the words in the sentence)
  - Results on test corpus 19.237 sentences 146.497 words (supertagging >> parsing):
    - 1 supertag 2'53'' 40% correct (9 ms/sent., 1.18 ms/wd)
    - 10 best supertags 48'34'' 70% correct (151ms/sent., 20ms/wd)

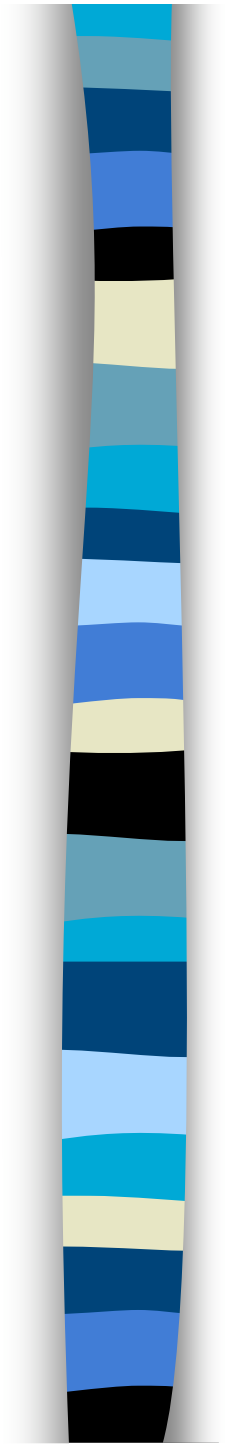
Discussion: practical state of the art

- Benoît Sagot, Eric de la Clergerie LFG parsing
  - Corpus EASy (Evaluation des Analyseurs Syntaxiques) Newspapers, web, mail, political speeches, literature,…
    - 87177 word occurrences
    - 4322 sentences (20,2 words per sentence)
  - Handwritten LFG grammar
  - Selects one parse per sentence
  - Parsing time: total 152s, 35ms/sentence 1,7ms/word
    - Correct chunks: 86%
    - Correct relations: 49%

Discussion:how to compare different practical states of the art

1. Mainly written
2. Rather long sentences ~ 20 words
3. Flat annotations
4. Hand written grammar
5. Lexical Functional Grammar
6. Correctness measure: results on chunks

1. Spoken
2. Very short but tricky sentences <10 words
3. Deeply annotated
4. Automatically acquired grammar
5. MultiModal Categorial Grammar
6. Correctness results on whole parse structure



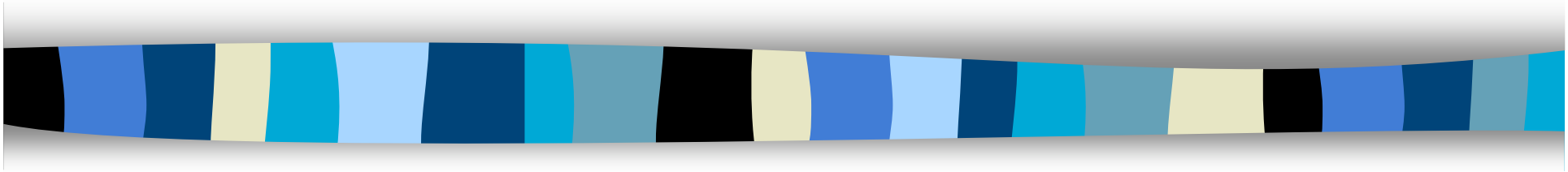
Tree grammars

- Strings are not enough:
  - For learning
  - For interpreting sentences

- Graphs (proof-nets of categorial grammars, dependency graphs) would be much welcome

…….but let's start with trees.

Tree grammars



(that I am just discovering,
be indulgent)

Context-free tree grammars (Engelfriet after Fisher)

- A ranked signature of terminals
- A ranked signature of non-terminals
- Productions rules of the form

$$A(x_1, \ldots, x_n) \quad \rightarrow \quad t(x_1, \ldots, x_n)$$

  - where A non terminal of arity n
  - where t tree over terminals and non terminals with variables $x_1, \ldots, x_n$

Regular Tree Grammars Thatcher, Doner, 1967

- Rules only for non-terminals of rank 0 (ONLY LEAVES rewrite)
- These tree languages exactly are the ones definable in monadic second order logic
- Their yields are context free strings languages

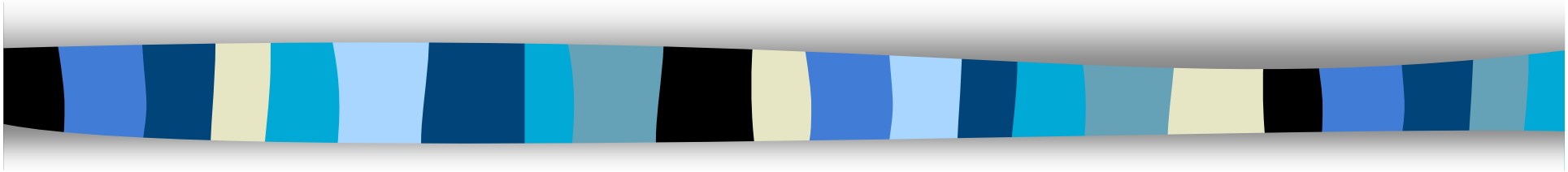
Context Free Tree Grammars Fisher 1968, Engelfriet 1977

- **OI** (~ unrestricted) only the highest non terminal undergo rewriting.
  Strings: indexed languages
- **IO** only the lowest non terminals undergo rewriting.
  Strings: LCFRS (incomparable)
- Monadic (always a single NT)
  CFTG (IO=OI) ~ TAG derived trees

Context free Hyper Edge Replacement Grammars Courcelle 1987, Engelfriet 1990

- Non terminal: hyper edges (ordered with possible repetitions)
- External vertices
- Replace an hyper edge with one with the same external vertices, possibly with new hyperedges linking them

Where are the tree languages that I like?



Categorial grammars

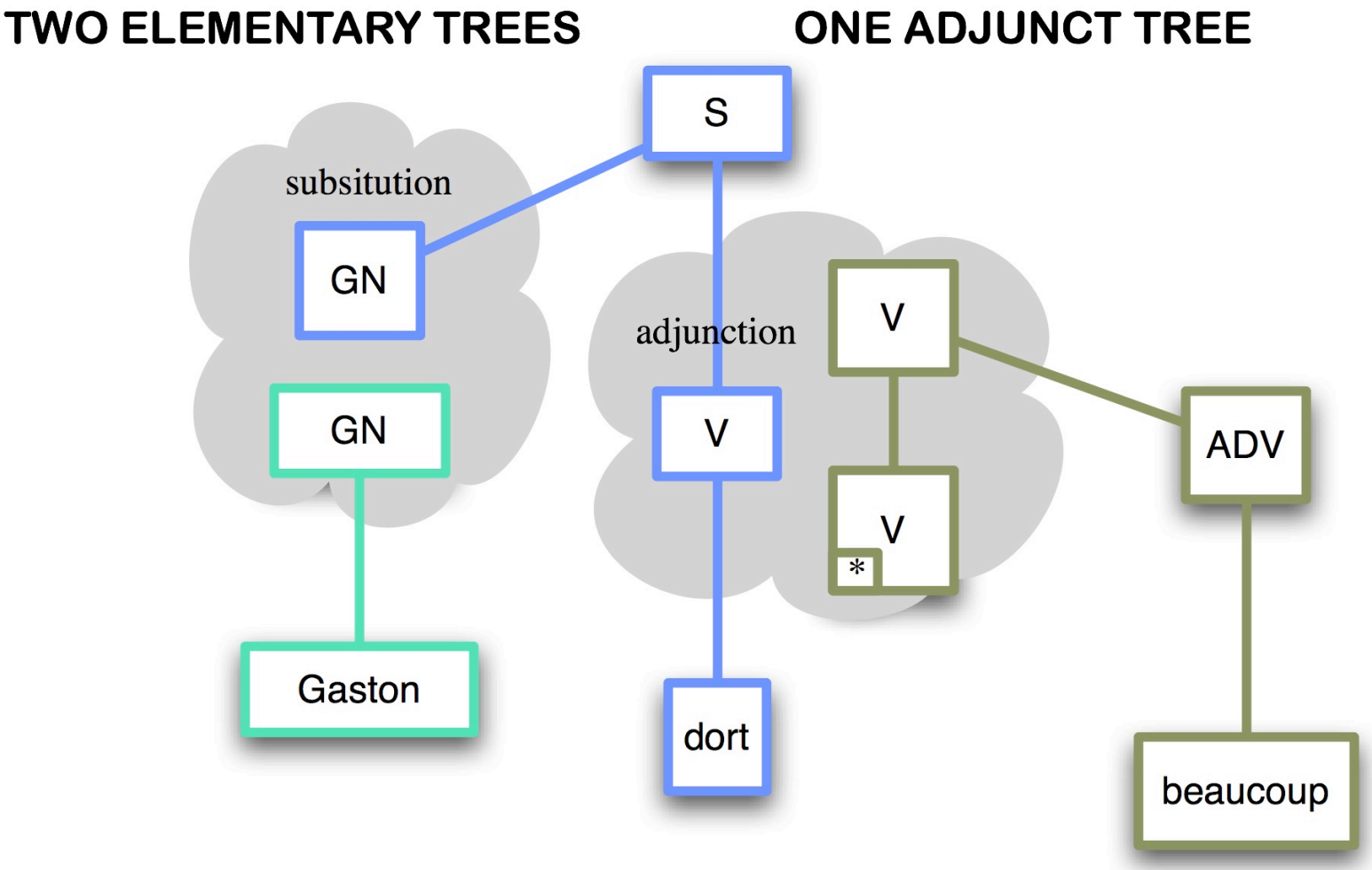
A word on the popular TAGs

Minimalist grammars

Categorial grammars

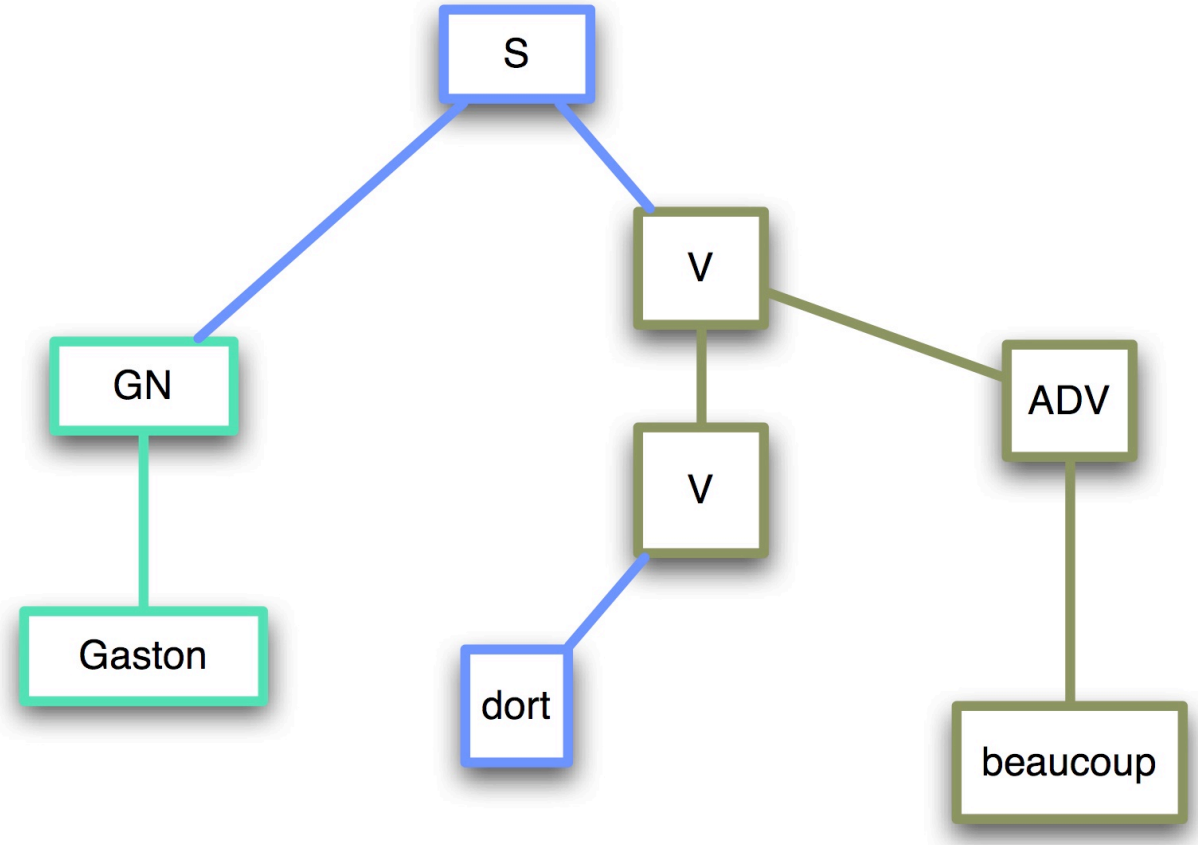
- Old notion: parse tree: any proof tree
  any bracketting is possible…
- Normal natural deduction only (Tiede)
- Non associative Lambek calculus
  - RTG Tiede 1999 (?), Kandulski 2006
  - ACG encoding Salvati Retoré 2007
- Associative Lambek calculus
  - RTG are not enough
    (despite CF string languages only)
  - CFTG? / HRG?

Tree adjoining grammars



Tree adjoining grammars

Performing the substitution and the adjunction yields: "Gaston dort beaucoup"



Stabler's minimalist grammars

- Close to categorial grammars or linear logic but much richer
- Implements Chomsky's minimalist program
- Lexicalised
- Two operations
  - Merge (binary)
  - Move (unary)

Minimalist grammars

- Trees with a head “<“ or “>” on internal nodes, indicating where the head is.
- Complete trees: a single c on the head, only words on other leaves
- Sequences of features on the leafs
  - Selection
    d n v …….
    =d =n =v …..
  - Movement
    +wh +k ….
    -wh -k …

Lexical items sequence of features associated with a word, possiby empty

Minimalist grammars

- Merge
  - a tree t with head =x w
  - Another tree t' with head xw'
- Result

  suppress the x and =x yielding $\underline{t}$ and $\underline{t'}$
  the selector si the head
  the selected is not

  $<(\underline{t} ; \underline{t'})$ if t is lexical (a leaf)

  $>(\underline{t'} ; \underline{t})$ if t is a real tree

Minimalist grammars

- Move
  - a tree t[t'] with head +f w and a subtree t' with head -f w
- Result

  supress the +f and -f yielding t and t'
  the context is the head

  $>(\underline{t'} ; \underline{t}[\varepsilon])$

Minimalist grammars: lexicon

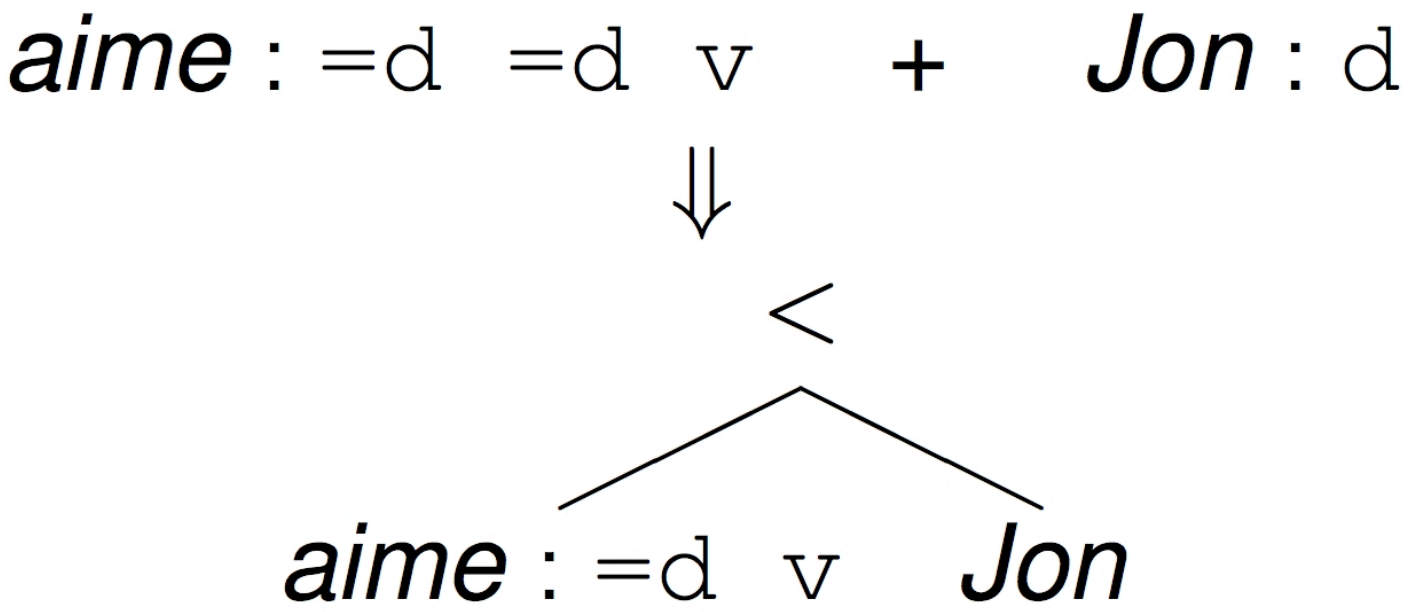
Jon : d

aime : =d =d v

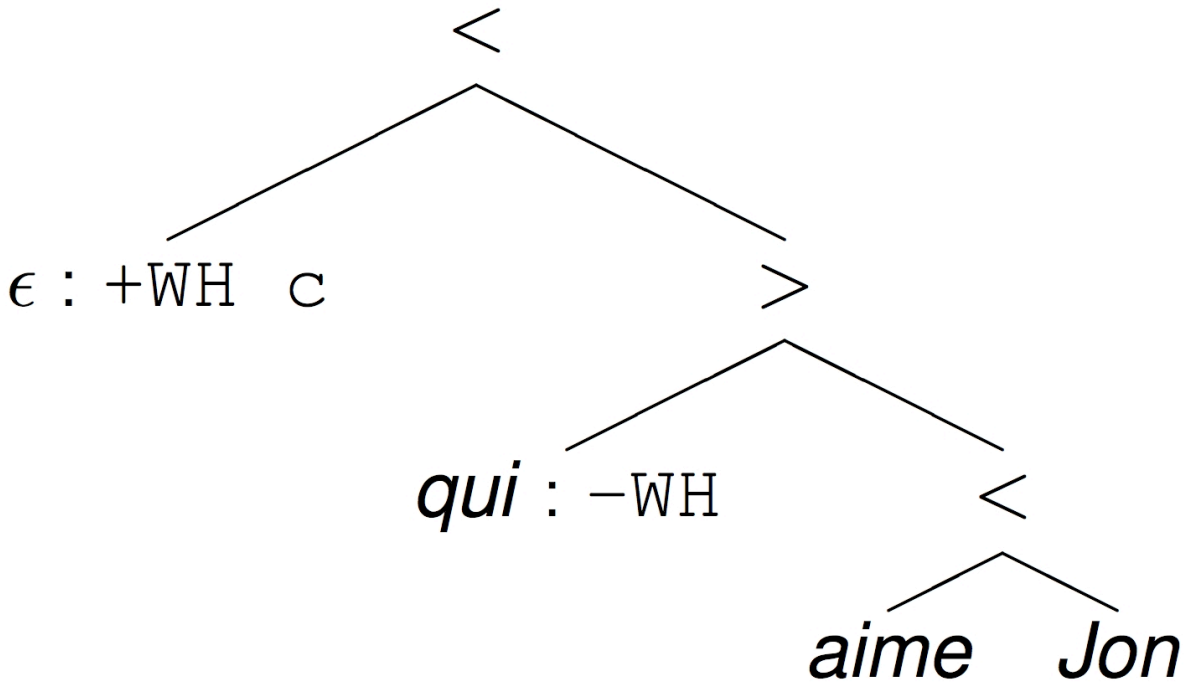
qui : d -WH

ϵ : =v +WH c

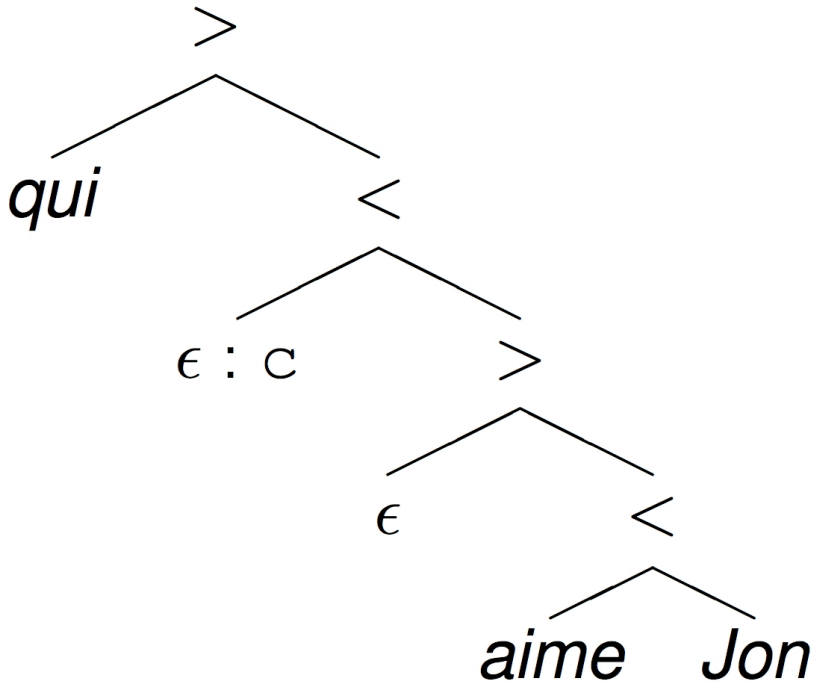
Minimalist grammars: merge



Minimalist grammars: merge



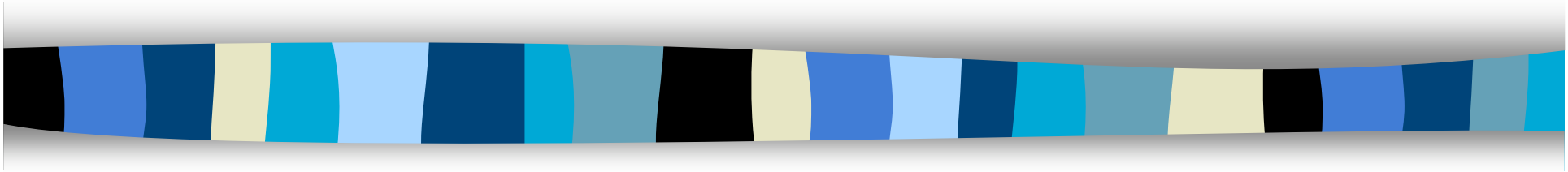
Minimalist grammars: move



Shortest move condition SMC

- Chomsky: whenever two subtrees (-f) are competing for a movement triggered by (+f), the one closest to the attractor (+f) moves.
- Stabler: whenever two subtrees (-f) are competing for a movement triggered by (+f), the derivation crashes. Strong SMC !

Minimalist tree languages in the hierarchy



As the image by a transducer of a regular language

Two step description

Mönnich, Morawietz, Michaelis

- If minimalist tree languages are complicated, can we describe them as the image by a simple mechanism of a simple set of tree languages.
- MG->MCFG
- Lift -> RTG (derivation trees)
- Walking Tree Automaton computing dominance, precedence of the MG derived trees

A more direct description hierarchically lower

Kobele, Retoré, Salvati

- Derivation trees (regular set):
  lexical, move(_) merge (_,_)
  Tree tuples
  [main tree, (-f_1 subtree), …., (-f_n subtree)]
  Strong SMC at most one subtree per f_i
- Eliminate the derivations that fail (still regular)
- Defined move and merge on tuples of trees
- Can be done with a Linear Deterministic Mult. Bottom-Up Tree Transducer

Merge with tuples of trees

$$(t_0[= xw], t_1, \ldots, t_n) \quad (t'_0[xm], t'_1, \ldots, t'_n)$$

- Compute $< (\underline{t_0}, \underline{t'_0})$ or $> (\underline{t'_0}, \underline{t_0})$
- Put the trees in the tuple, and if there are two trees whose head starts with the same -f, the derivation crashes. (Strong Shortest Move Condition)

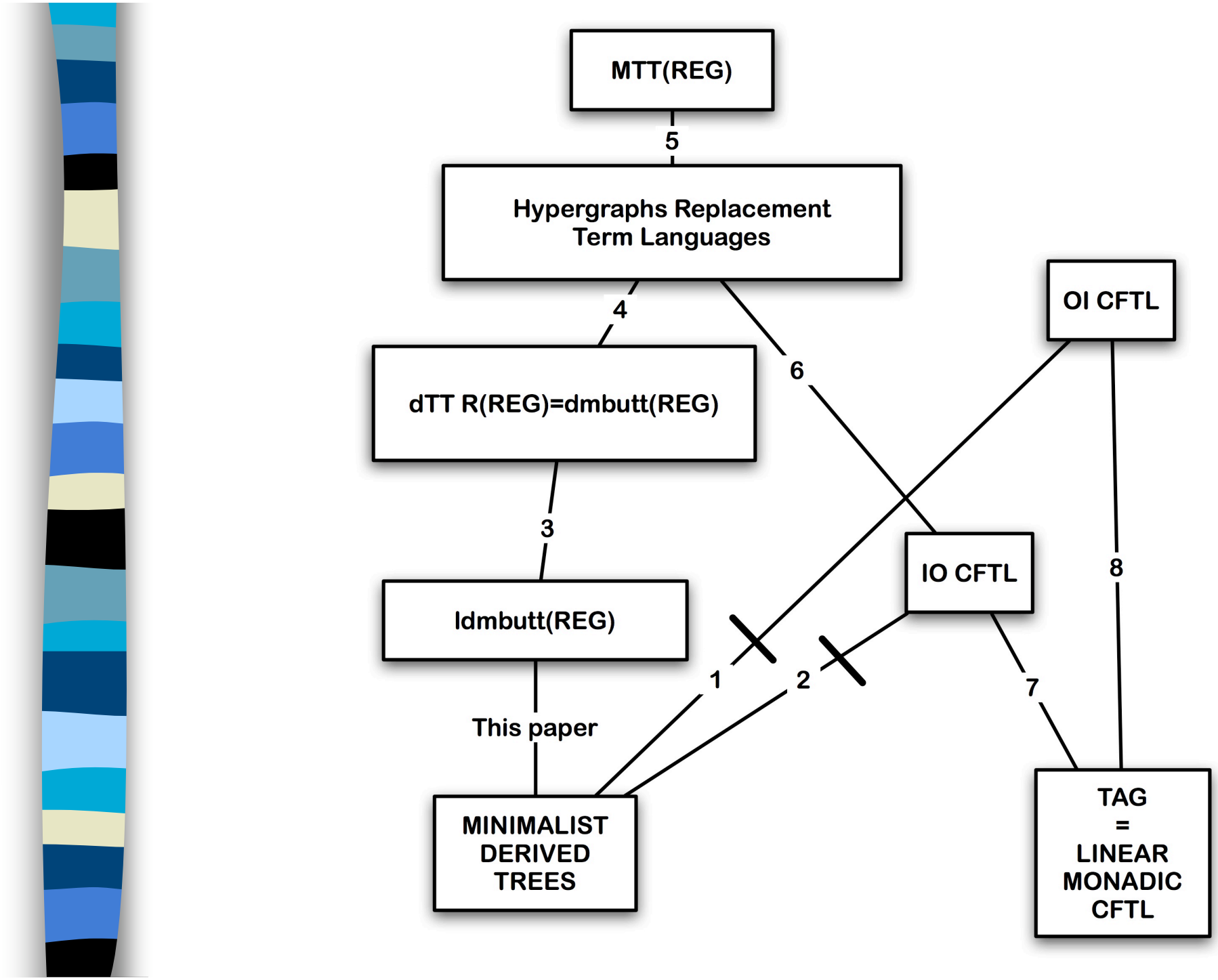
Move with tuples of trees

$$(t_0[+f_i w], t_1, .., t_i[-f m], \ldots, t_n)$$

- Compute $> (\underline{t_i}, \underline{t_0})$
- Put the trees in the tuple, and if there are two trees whose head starts with the same -f, the derivation crashes. (Strong Shortest Move Condition)

Interpreting this result

- Filtering the wrong derivation tree yields a regular tree language (bottom up automaton)
- The computing of the derived tree ensures to be included into HR CFG (technical horrible reason: a top-down tree transducer with regular look-ahead and finite copying can do what a linear deterministic multi bottom up tree transducer does)


MTT(REG)
5
Hypergraphs Replacement
Term Languages
4
6
dTT R(REG)=dmbutt(REG)
3
ldmbutt(REG)
This paper
MINIMALIST
DERIVED
TREES
OI CFTL
IO CFTL
1
2
7
8
TAG
=
LINEAR
MONADIC
CFTL

Conclusion

- Admittedly, little is know, but we're learning and starting to clear the picture.
- At least we know where stands a formalisation of a/the main linguistic theory
- Improving the connexion between logical formalisms and rewrite formalisms
  - Syntax / Semantics correspondence
  - Parsing efficiency (kind of compilation)

Some references

- Edward Stabler A derivational approach to minimalism. In LACL Springer LNCS 1996
- James Rogers *A descriptive approach to language complexity* CSLI 1998
- Frank Morawietz *Two step approaches to natural language formalism* Mouton de Gruyter 2003
- Greg Kobele, Christian Retoré, Sylvain Salvati: An automata -theoretic approach to minimalism in *Model Theoretic Syntax at 10.* ESSLLI 2007
- Christian Retoré Les mathématiques de la linguistique computationnelle. Premier volet: la théorie des langages. *La gazette des mathématiciens,* Société mathématique de France. 2007

- **Happy birthday Gérard**