Variadic (n-way) Unification

status update and preliminary results

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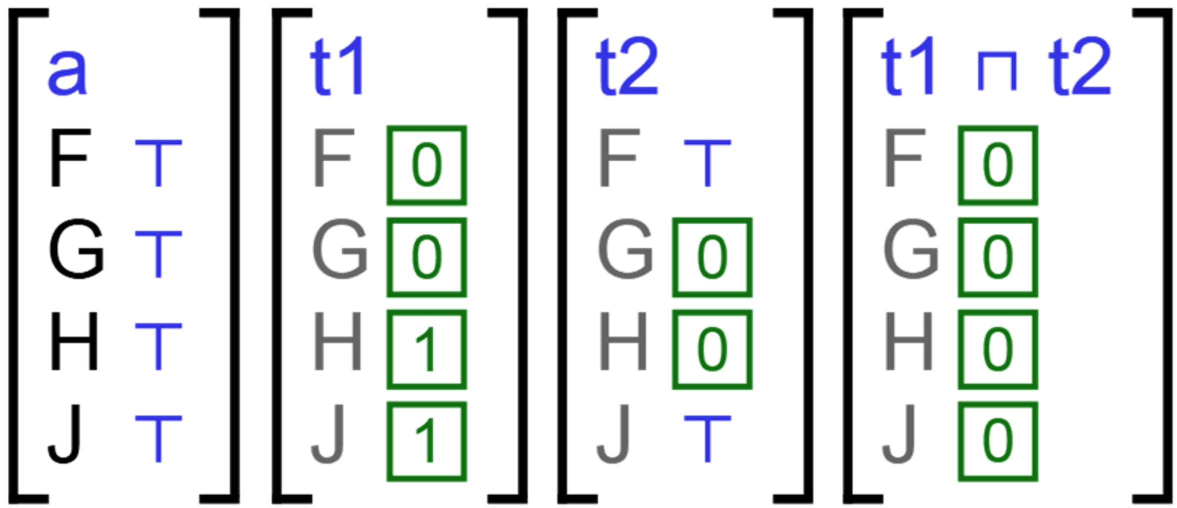
Summary

- Unification is by far the most expensive part of parsing
- PET and LKB implement Tomabechi's (1991, 1992) "quasi-destructive" method
- I investigate a new algorithm where the fundamental recursive function accepts node arguments in variable arity
- The method is implemented in *agree*, a new DELPH-IN parser
- Early results are promising, especially during unpacking, where all rule daughter positions can be unified at once
- n-way unification outperforms a Wroblewski (1987)-style incremental unifier in controlled intra-system evaluation
- Unification satisfiability checker pseudo-code:
  `http://www.agree-grammar.com/n-way-unification/satisfiability.html`

What makes TFS unification difficult?



- Coreference spreading: The unification of *t1* and *t2* equates two coreference equivalence classes which remain distinct within *t1*
- This process can continue to chains of arbitrary length

Pereira 1985

"A Structure-sharing representation for unification-based grammar formalisms"

- Basic unification algorithm (from theorem proving work in the early 1970s) remains unchanged
- Instead, the underlying graph representation is changed to reduce the amount of new structure written
- This is done by maintaining each TFS as an $\langle update, skeleton \rangle$ tuple
- Applying updates incurs penalties when the derived instance is accessed

Wroblewski 1987

“Nondestructive Graph Unification”

- “Incremental” unification
- Build new structure as needed to avoid destroying old
- Generation counter invalidates all temporary structures associated with failed work in a single operation
- Incremental algorithms inherently suffer from “over-copying”

☞ For comparison with n-way, *agree* includes a (thread-safe) incremental-type unifier (results in this presentation)

Tomabechi 1991, 1992

With structure sharing adaptation (Malouf 2000)

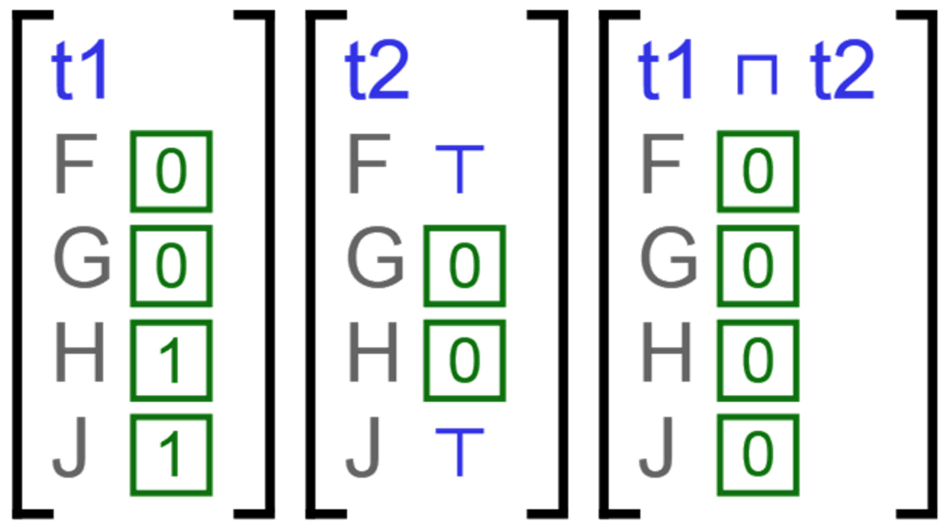
- This has been regarded as the state-of-the-art method for 20 years
- Unification is divided into two passes
  1. with no allocations, prepare data structures
  2. if successful, write new TFS
- Scratch fields are invalidated by Wroblewski's global counter technique
- Disadvantages:
  – As published, it is not thread-safe
  – Successful unification requires two passes

Other authors

- Godden (1990) "Lazy Unification" relies on language closures
  - Inefficiencies of this language construct probably nullify gains
- Emele (1991)
  - Extending Pererira's update/environment ideas; backtracking
- Kogure (1990, 1994)
- Tomuro and Lytinen (1997)
- Van Lohuizen (2000)
  - parallel adaptation of Tomabechi

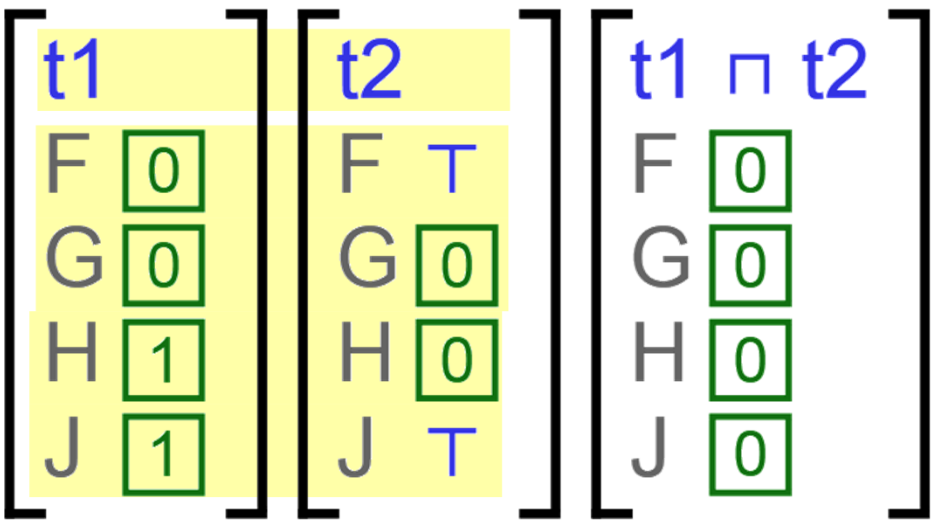
n-way unification: idea

- Observation: complexity in existing algorithms owes to the maintenance of temporary structures to account for pending equivalence classes that are subject to further spreading



- At each step, a duplex (two-argument) unifier can only join a single element to the class. Therefore:
  - scratch structures reflect the complexity of an arbitrary limitation
  - the number of recursive calls is unnecessarily high

duplex unification



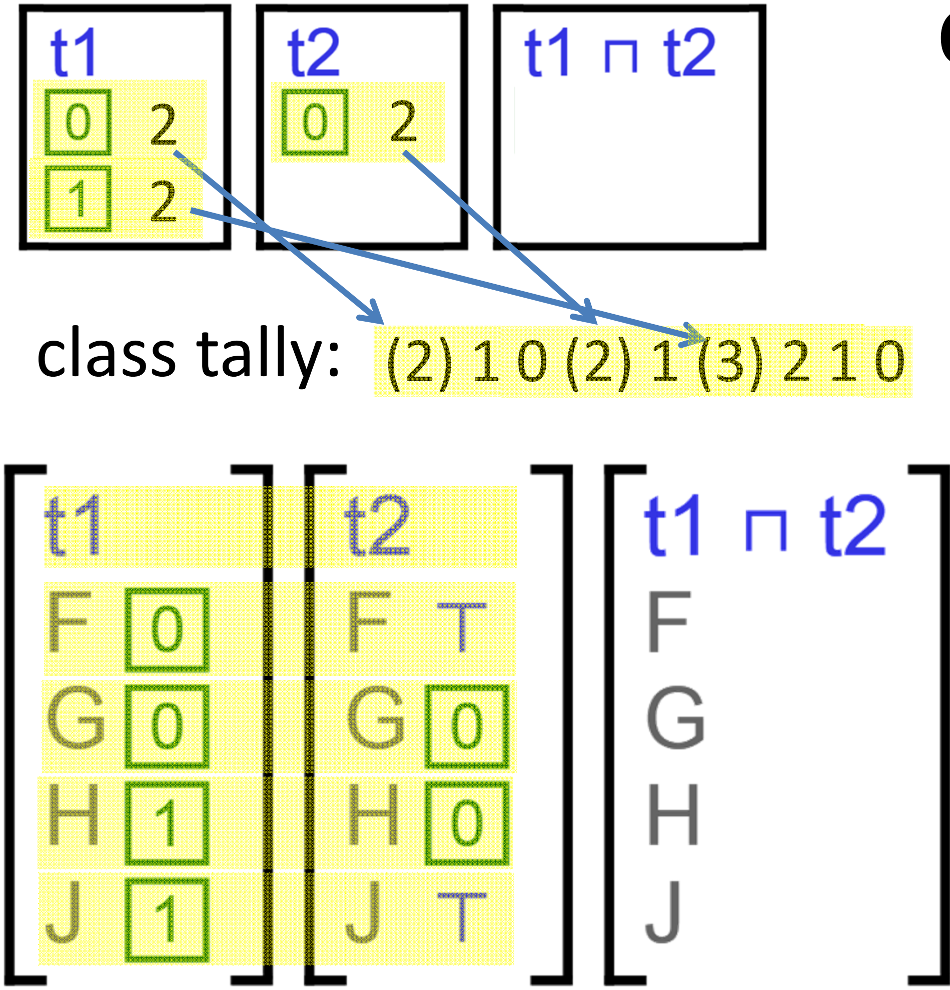
1. *unify*(t1, t2)
   F
   G
2. unify(t1-F/G, t2-G/H
   H
3. unify(#2, t1-H/J)
   J

The number of recursive calls in a top-level unification is $O(n)$ in the number of coreference equivalence classes in the *input* (3 in this case)

n-way unification

- It would preferable to unify the entire equivalence class at once, in a single function call
- Delay descent on the class until the equivalence class is definitive
- Only then, unify all nodes in the class and enter their sub-structure all at once
- To do this, a set of reentrancy tallies—invariant for each top-level TFS—is maintained and referenced during unification

example

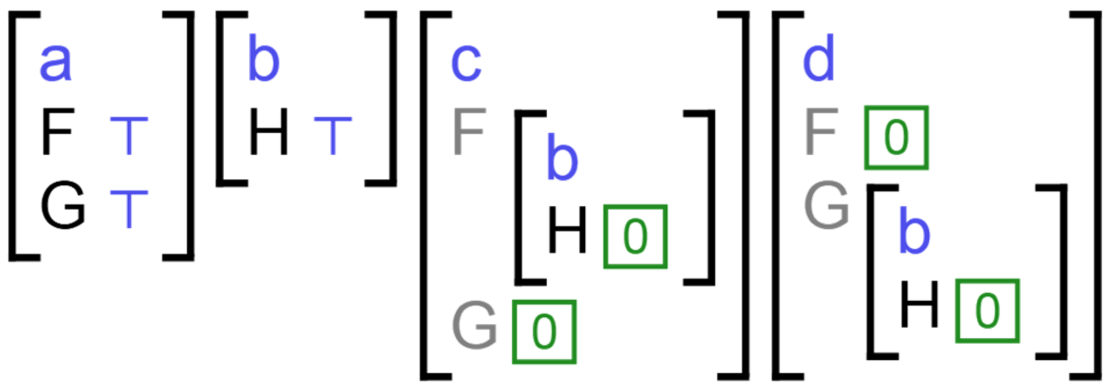


1. *unify*(t1, t2)
   F
   G
   H
   J
2. *unify*(t1-F/G,
   t2-G/H,
   t1-H/J)
3. completeness-check

The number of recursive calls is $O(n)$ in the number of equivalence classes in the ***output*** (2 in this case). In unification, the number of output classes is always $\leq$ the number of input classes.

n-way completeness check

- When the traversal is complete, remaining reentrancies for all classes must be zero
- If any are not, this indicates that parts of one or more inputs were not visited
- Unvisited parts occur when there are mutually-blocking structures:



- This condition is a true-positive for unification failure
- The cost of the check—$O(n)$ integer tests for zero, in the number of input classes—is only borne for putative successes

Determinism guarantees

- For inputs that can be unified:
  - when any classes remain, at least one of them will be exposed and completed
  - such a class will always be accessible via a prospective (not yet visited) node
- The completeness check is the key to the single-traversal guarantee:
  - n-way unification requires only one single, step-wise traversal of the input TFSes, greedily descending only on completed classes
  - Traversal order—for discovering the exposed, completed classes—is irrelevant

Space analysis - satisfiability

- For satisfiability checking, the class list, plus a single integer tally is the entire scratch requirement
- Worst-case $O(n)$ in the number of input classes
- Best case $O(n)$ in the number of output classes
- For best performance, *the class lists are directly maintained in the variadic format of the (eventual) recursive call*

Persistent space analysis

- Tally sets are an additional persistent storage cost for each top level TFS
  - $O(n)$ in the number of coreferenced nodes
  - agree uses 1 byte tallies, allowing a single coreference to have up to 255 reentrancies
- Computing these tally sets are a “free” product of the unification that produces any TFS
- But they require administration: a more generally pervasive association between nodes and their top-level TFS
  - However, carrying this association also solves the problem of spurious structure sharing (Malouf 2000, aka theorem proving’s “renaming problem” Pereira 1985)
  - Consistently distinguishing nodes by $< TFS, node >$ tuple within the unifier allows aggressive (extra-linguistic) structure sharing

Implementation options

- Class lists can be discarded after descent is undertaken
- In the minimal requirement, type unification (in addition to descent) is deferred until the class is definitive
  - Depending on storage details, this may incur extra node accesses
  - This increases the number of failures detected solely by the completeness check
  - To detect overall failures earlier, and avoid extra node accesses, it is trivial to maintain a running type unification with each class
  - For the above reasons, *agree* implements this variation

Extending the n-way satisfiability checker to the full case of writing the result TFS

- For each class, also maintain a list of referring nodes
- In the *agree* implementation, this is a linked list which adds time $O(1)$ and space $O(n)$ in the number of input classes
- When a coreferenced node is definitively "published," an $O(n)$ walk of the list writes all of its inward arcs
  - This is trivially deferred until unification success is known

agree: n -way full implementation notes

- The *agree* implementation is vastly complicated by simultaneously implementing the parse restrictor, so that restricted nodes are never written in the first place
  - Only referring nodes in non-restricted areas are recorded in the class
  - Traversal into restriction is still required, so writing is switched off when entering restriction—but then back on when popping out of any coreference that is not subject to restriction
  - The re-enabling case is detected by the presence of > 0 referring nodes
- Sharing the invariant tally set amongst rule daughters is ok, but may lead to reentrancy tallies of ‘1’, which can be ignored

Unification in DELPH-IN parsers

- The LKB and PET use Tomabechi's method
- van Lohuizen (2000) made some modifications to PET to support concurrent unification
  - is this version still supported?
- *agree* is a new parser supporting DELPH-IN research standards
- *agree* supports two unifier test configurations
  - incremental (duplex) unifier
  - new n-way unifier (with running type carry)
  - both are thread-safe, supporting intrinsic concurrency when or if the parser initiates multiple tasks

Evaluating n-way unification

- When testing diverse parsers, it is not possible to decisively control for performance of the unification algorithm alone
- Comparative evaluation of distinct parsing systems is already notoriously difficult (Dridan 2010)
- This is true even with identical grammars and testsuites

  Uncontrolled variables include: operating system; programming language; compiler options; runtime environment; storage and access methods for GLBs, type hierarchy, and TFS; parser configuration options; and numerous internal parser implementation details, such as chart storage, chart access, etc.
- Therefore, conclusive evaluation of n-way unification requires intra-system testing
  - An incremental unifier is in place in the *agree* system (results today)
  - An in-system quasi-destructive unifier must be implemented (work underway)

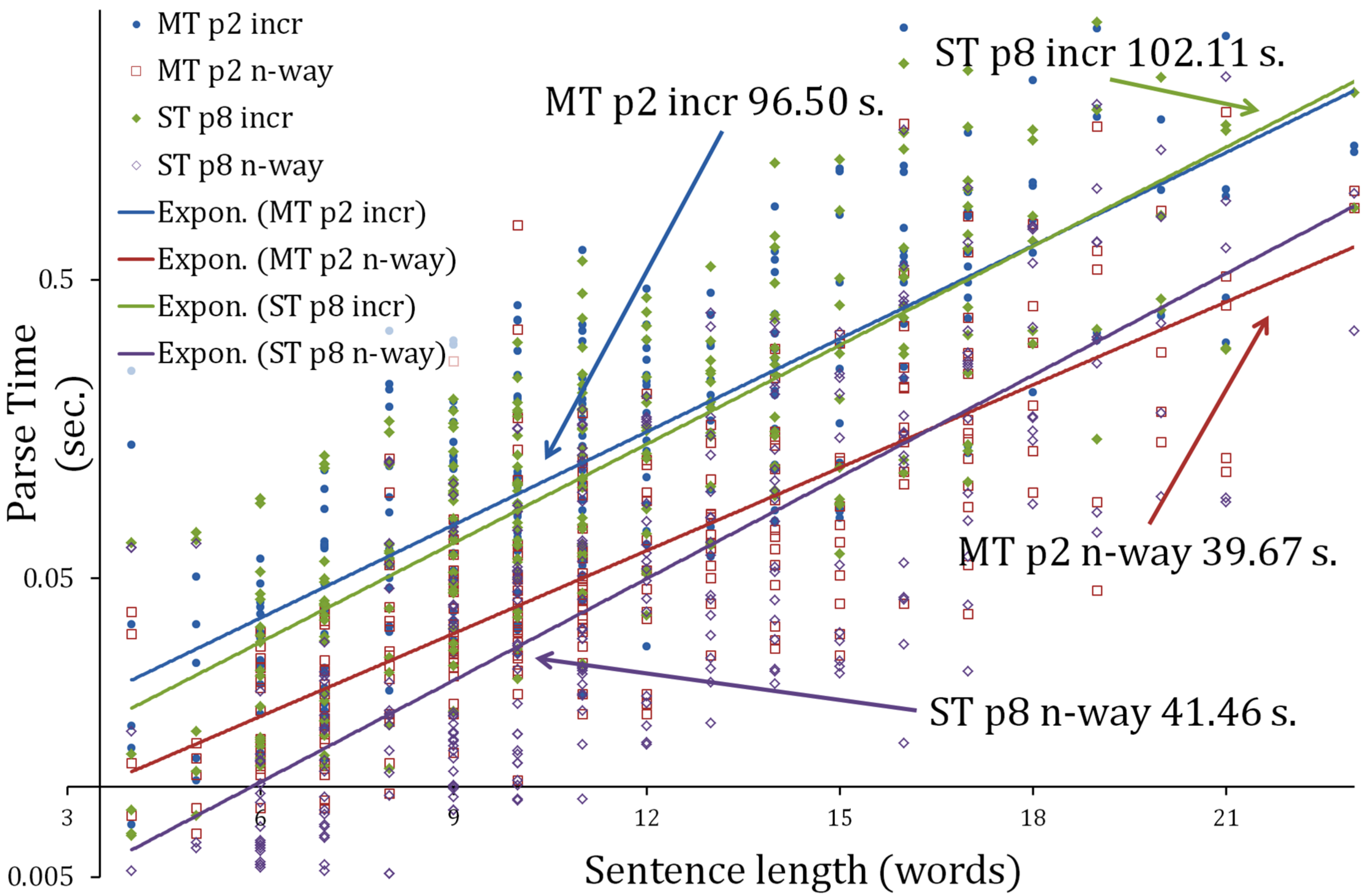
Evaluation methodology

- ERG rev. 8962
- ‘Hike’ corpus
  - except sentences containing numerals (287 sentences)

  http://www.agree-grammar.com/corpora/hike/hike-input-PET.txt
- Full packing, exhaustive unpacking
  - *agree* currently does not support parse selection
- Windows Server 2008 x64
- .NET 4.0
- gcServer
  - this is a more intrusive, but higher-performance garbage collector
- Hardware: 8-way (2 × Xeon 5460), 3.17GHz, 32GB

incremental duplex vs. n-way unification, $\log t$

agree parser: multi-threaded, pipeline 2 vs. single-threaded pipeline 8

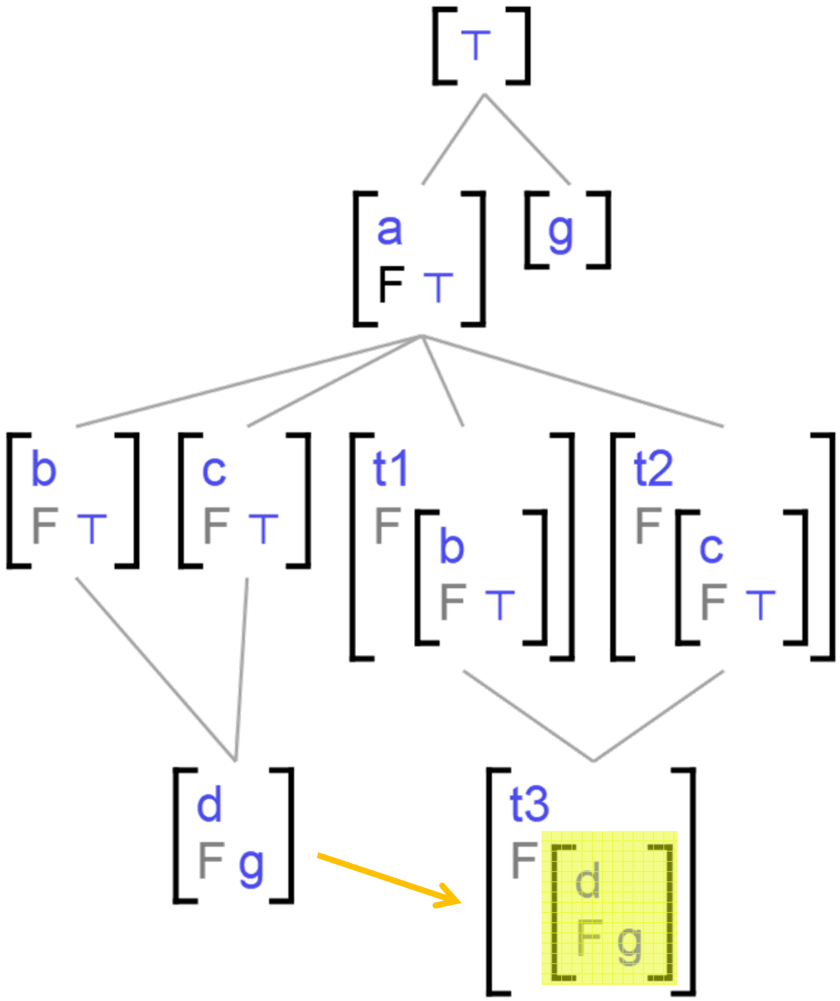


n-way: Opportunities in the parser

Although experiments evaluating the intrinsic performance of n-way unification continue, the algorithm does enable at least two intriguing operational benefits:

1. Simplified treatment, during unification, of well-formedness constraints
2. Synchronous unification of all rule-daughters during unpacking

Well-formed unification



Our formalism enforces *well-formedness* during unification. Because the type unification of *t1* and *t2* yields a third type, *t3*, unification must automatically introduce the canonical constraint on *t3* as well. Therefore, *t3* ends up with *g* for feature F, even though this constraint is specified by neither *t1* nor *t2*.

Evaluating well-formedness checks with n-way unification

- With the ERG 'Hike' corpus, well-formedness checks account for 1.41% of duplex unification time
  - This was measured using the *agree* incremental unifier but the result should apply in general
- When n-way naturally incorporates well-formed constraints, their provenance is lost
  - This is the aesthetic benefit of the method…
  - …but it essentially precludes direct measurement of the improvement
  - However, any improvement would likely be small
  - Therefore, evaluation of this effect was not pursued

n-way and Unpacking

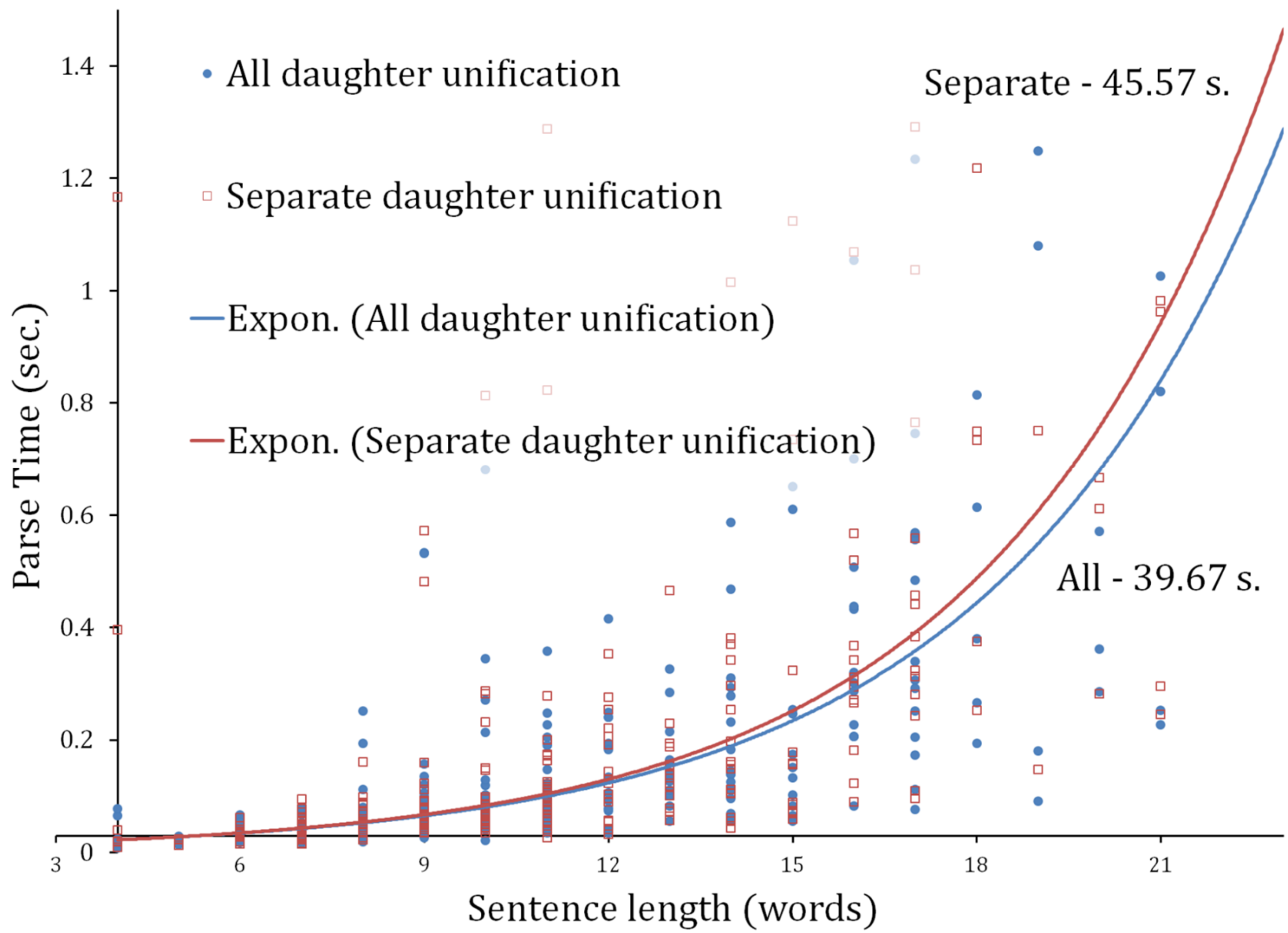
- n-way satisfaction checking trivially supports parse forest validating with $O(1)$ top-level unification operation per derivation
  - In practice, memoization at each level of the tree is desired, so $O(n)$ operations would be used per derivation
- Duplex unifiers require $O(n)$ in the rule arity *for each node* in the derivation tree
  - Memoization is not opt-out, so, $O(n^2)$ operations per derivation

Evaluating n-way synchronous unpacking

- Test n-way unification with and without synchronous unpacking, in the *agree* parser
- Synchronous unpacking was 13% faster over the whole corpus
- As expected, maximum improvement was for longer sentences, as high as 94%

Results: synchronous unpacking

agree parser, n-way unification, multi-threaded, pipeline 2



Future work

- Intra-system evaluation of n-way vs. quasi-destructive unification
  - implement Tomabechi (1991, 1992) method in *agree*
- Exploit aggressive structure sharing potential in n-way unification

agree parser – overview and eval presented at breakout tomorrow

Thank you!

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