The Combinatorics of Merge and Workspace Right-Sizing*

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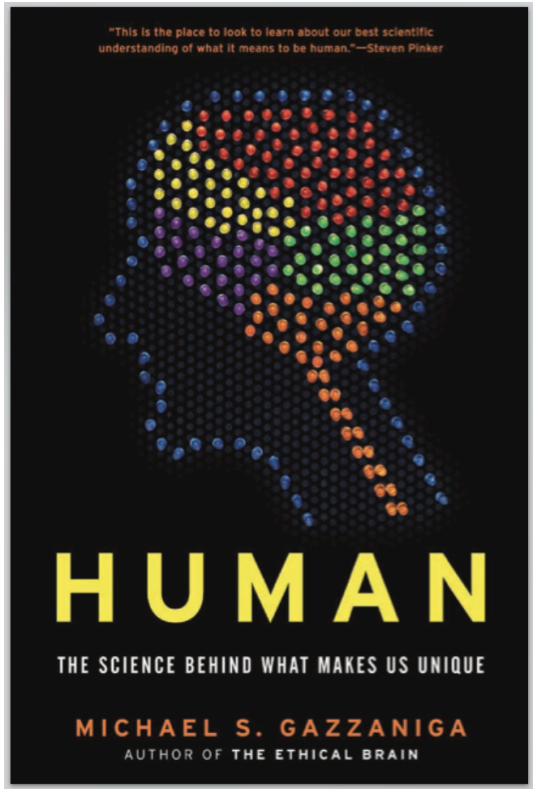
Being human: our brains

- Popular conception, e.g., Gazzaniga (2008), pg. 8: we congratulate ourselves on our brain power:
  - "I want to begin by simply recognizing the huge differences between the human mind and brain and other minds and brains […]"
- We posit:
  - The marvel we call the human brain is actually the weak link in our cognitive apparatus.



Sensory Apparatus

- Our sensory apparatus provides way too much information for the brain to process. There is ample biological evidence for this:
  - Our eyes:
    - have sensitivity down to the single photon level (Tinsley et al. 2016)
    - have peak acuity of 77 cycles/degree (Curcio et al. 1990)
  - Our nose:
    - sensitivity can be of the order of parts per billion (ppb) (Wackermannová et al., 2016).
  - Our ears:
    - eardrums can detect vibrations smaller than the diameter of a hydrogen atom (Fletcher & Munson, 1933).
- All completely unnecessary for survival.
  - [Dynamic range is huge: yet neurons can fire…]

Why such sensitivity?

- Evolutionary pressure unknown:
  - could be a simple matter of chemistry
- Anyway:
  - It's clear, in case after case, the brain does not make use of the full resolution of our sensory inputs.

Throwing away information

- Since we cannot cope with the sensory deluge, the brain tosses out most of the sensory information:
  - (attention puzzle) how to sieve the sensory information?
  - (dynamic range puzzle) yet we can report on single photons (above chance)
- Our hypothesis:
  - Same goes for language, the brain (must) economize where it can:
  - Chomsky (2005) terms the pressure for computational efficiency a Third Factor consideration.
  - This applies to the reduction of Merge to simplest (binary) Merge (cf. Komachi et al., 2019).

Resolution in Language

- Simplest Merge may follow directly from Workspace (WS) sizing constraints.
- Although simplest Merge (by itself) has demonstrably undesirable combinatorics (e.g. from an initial WS of just two lexical items, about 8 million distinct sets can be formed in just 8 Merges), language does not make full use of this resolution.

Workspace Size

- Merge (Chomsky 1995, 2013, 2015, etc.)
- Merge is free:
  - In {α, {β, ɣ}}, ɣ can undergo internal Set Merge or Pair Merge to form:
    - {ɣ, {α, {β, ɣ}}}
    - <ɣ, {α, {β, ɣ}}>
- If Merge is free, then how do you block an infinite number of Merges?
  - In theory, any SO can undergo internal or external Set Merge or Pair Merge an infinite number of times.
  - In theory, when generating a phrase, you have an infinite number of possible derivations.

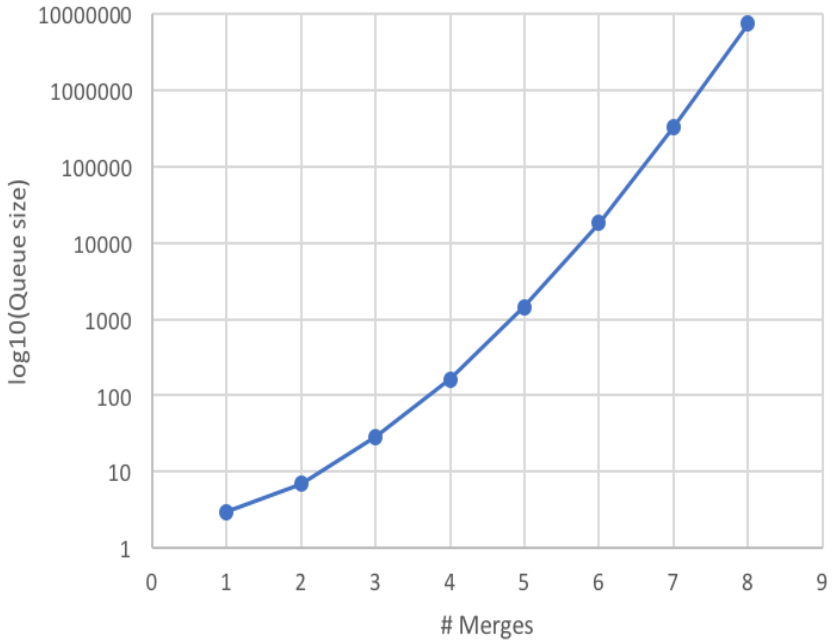
*From Fong and Ginsburg (2018)

Simple example: *the book*

#Merges	#SOs
1	3
2	7
3	29
4	161
5	1,423
6	18,144
7	318,480
8	7,396,976

# of possible Syntactic Objects as # Merges grows

*From Fong and Ginsburg (2018)



Log-scale graph of possible SOS as # Merges grows

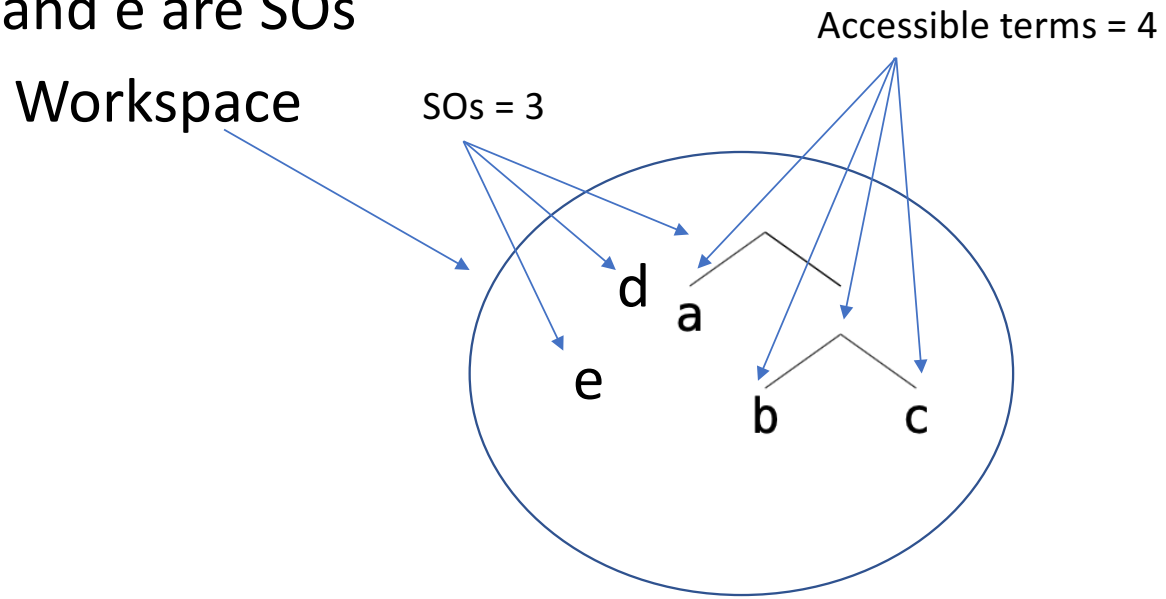
Free Merge must be constrained.

Workspace Right-Sizing

- Accessible terms in a workspace (Noam Chomsky, p.c.; Chomsky 2017 Reading lecture)
- WS = Workspace
- SO = Syntactic Object
- Define WS Size as # SOs + # Accessible terms
  - # accessible terms of a SO = number of proper subsets of the SO + lexical items
  - Subject to Minimal Search (lower copies not considered accessible)

Workspace Right-Sizing

- {a, {b, c}} is a Syntactic Object SO
- d and e are SOs

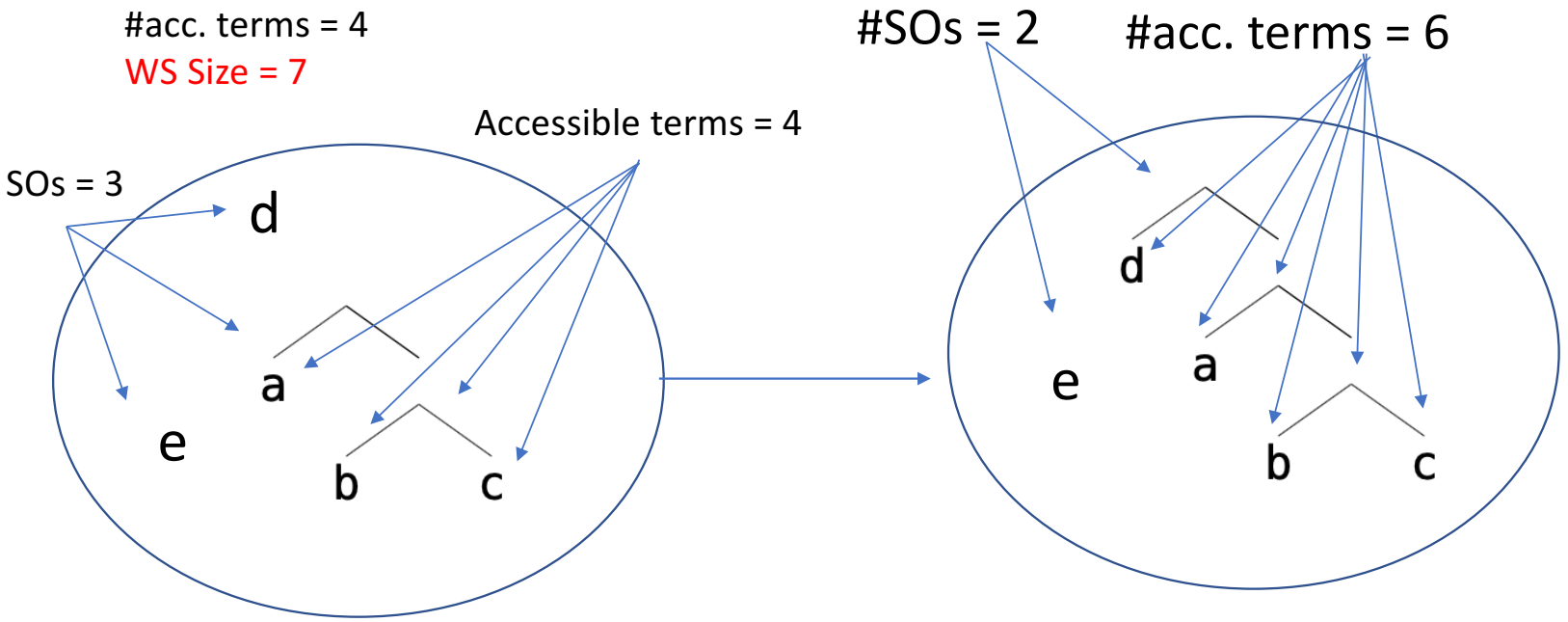


#SOs = 3
#acc. terms = 4
WS Size = #SOs + #acc. terms
WS Size = 3 + 4
WS Size = 7

Workspace Right-Sizing

- External Merge (EM) of d and {a, {b, c}}

#SOs = 3
#acc. terms = 4
WS Size = 7



#SOs = 2
#acc. terms = 6
WS Size = 2 + 6
WS Size = 8

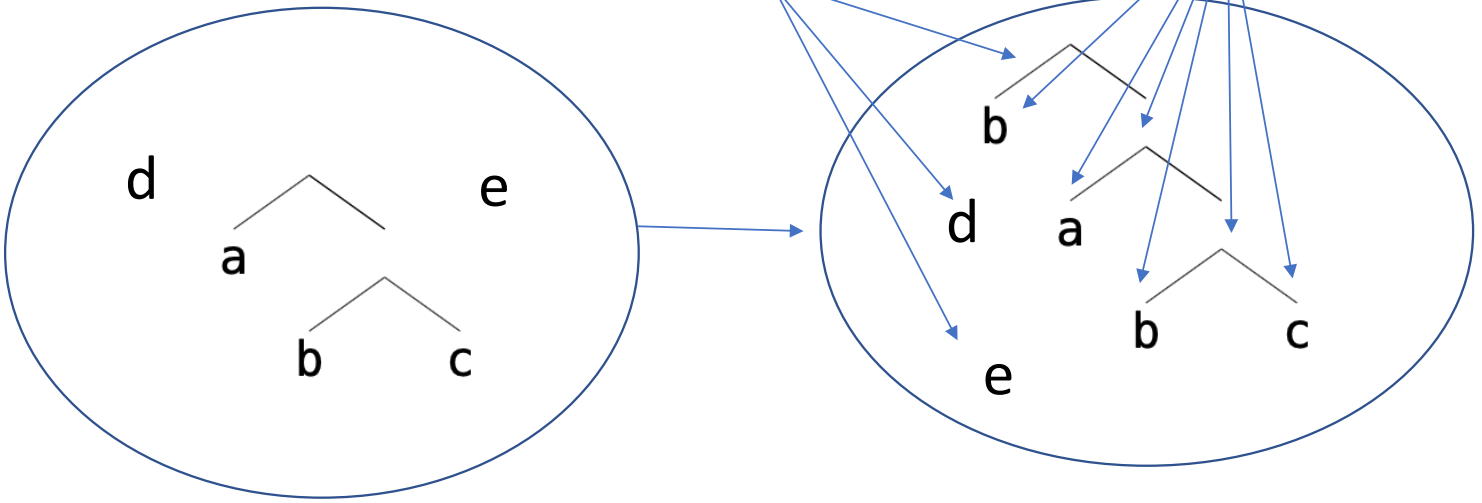
External Merge (EM) decreases the # of SOs by 1, but increases the number of accessible terms by 2.

EM increases WS Size by 1

Workspace Right-Sizing

- Internal Merge of b and {a, {b, c}}

#SOs = 3
#acc terms = 4
WS Size = 7



#SOs = 3
#acc. terms = 6
WS Size = 3 + 6
WS Size = 9

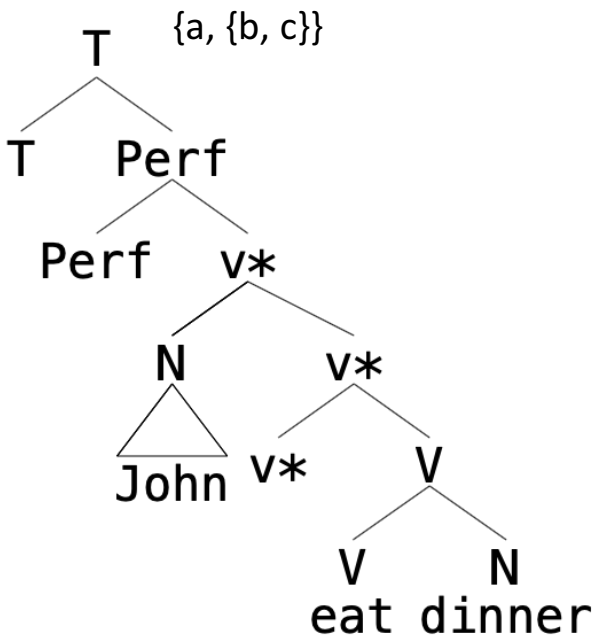
Internal Merge (IM) keeps the # of SOs the same, and increases the number of accessible terms by 2

IM increases WS Size by 2

Countercyclic Merge

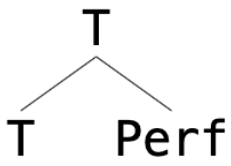
John has eaten dinner.

- Assume Perfective Merges counter-cyclically with T



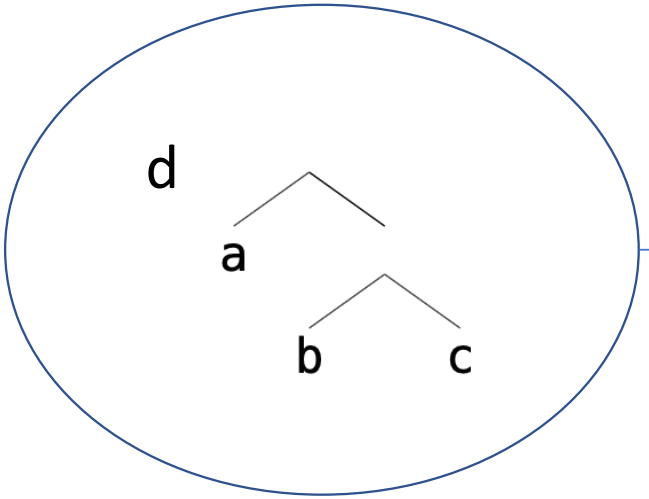
[{a, {b, c}},d] → [{a, c}, {a, {b, c}},d] (Huijbregts 2019)

{a, c}



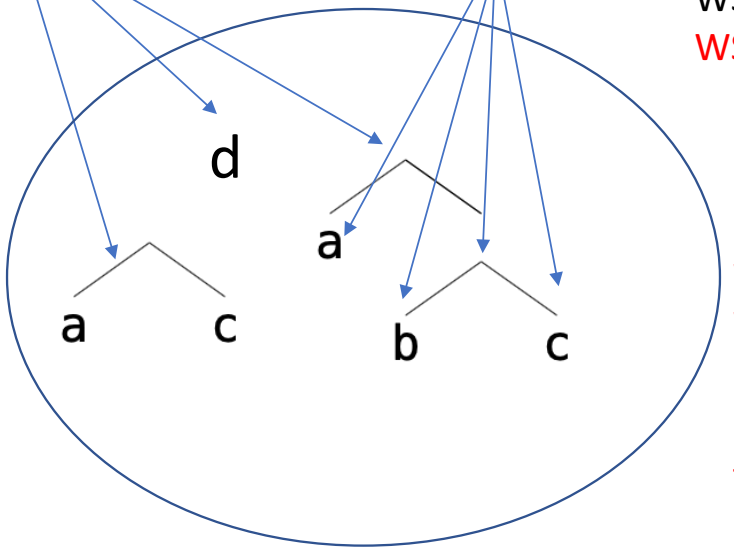
Countercyclic Merge

#SOs = 2
acc. terms = 4
WS Size = 6



SOs

acc. terms



#SOs = 3
#acc. terms = 4
WS Size = 3 +4
WS Size = 7

WS Size increases by 1
WS Size increase is okay

Is there any way to block this?

a is 1 acc. Term
c is 1 acc term

Proposal 1: Merge cannot decrease WS Size.

- You can’t remove anything from the WS.

Proposal 2: Copies are not accessible terms.

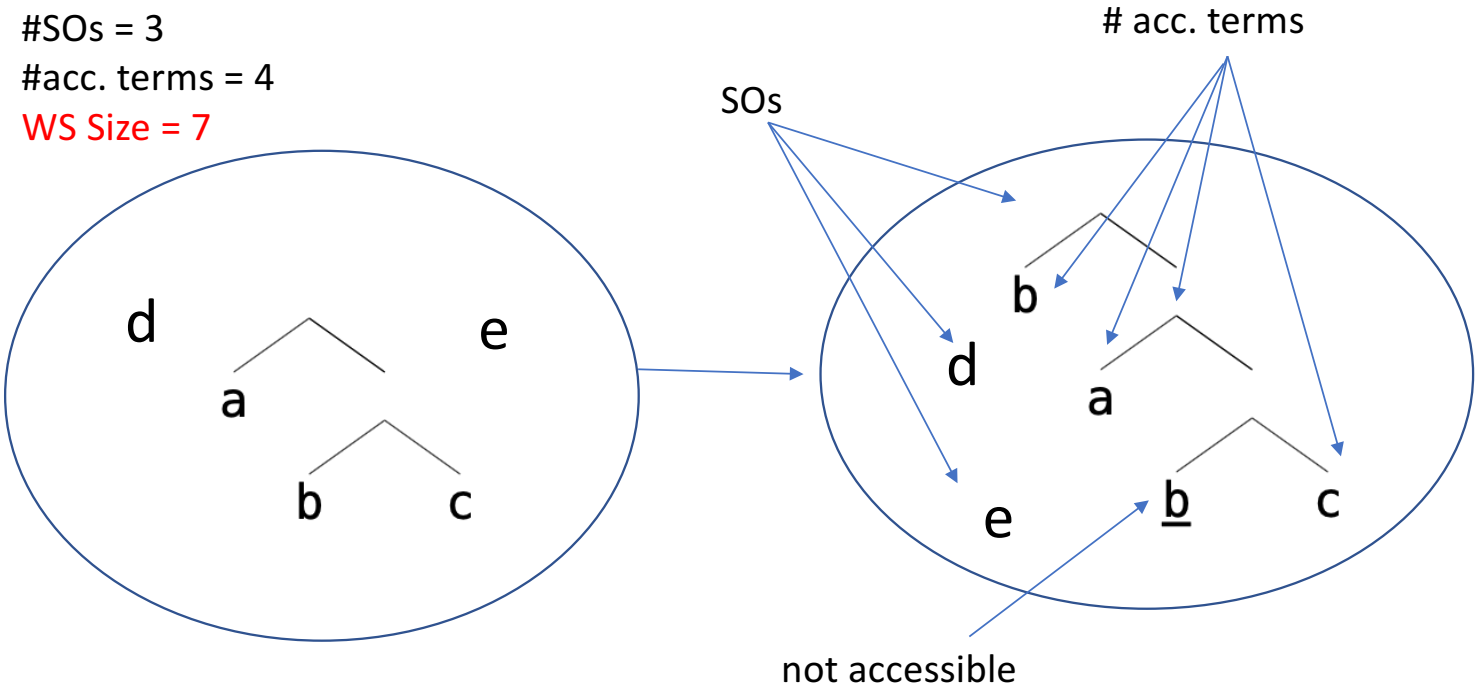
Workspace Right-Sizing

- Internal Merge of b and {a, {b, c}}

Minimal Search: exclude lower copies from set of accessible terms

- Copy of b is indicated as b

#SOs = 3
#acc. terms = 4
WS Size = 7



#SOs = 3
#acc. terms = 4
WS Size = 3 + 4
WS Size = 7

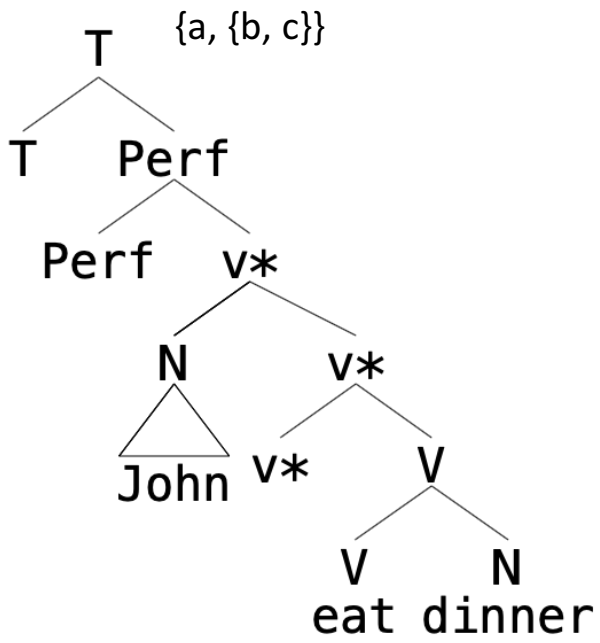
IM keeps the # of SOs and accessible terms the same.

IM does not change WS Size

Countercyclic Merge

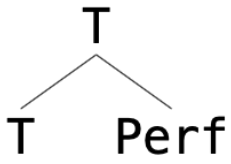
John has eaten dinner.

- Assume Perfective Merges counter-cyclically with T

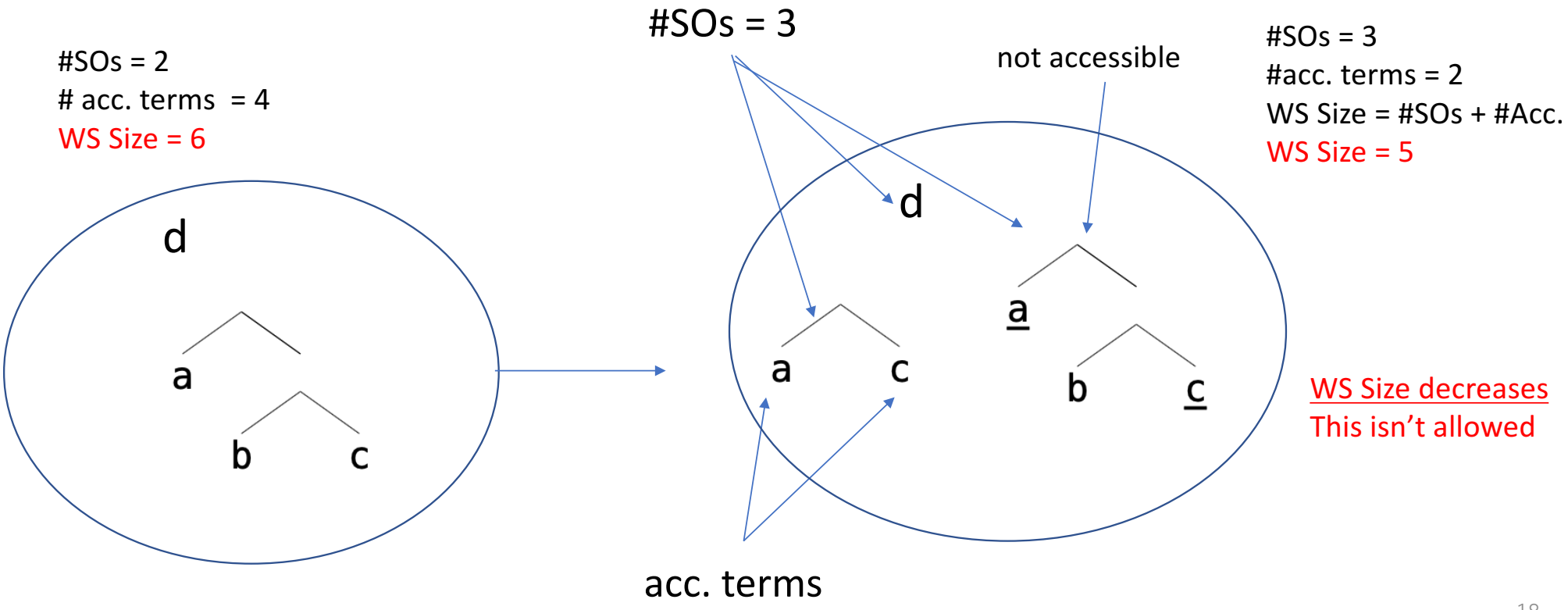


[{a, {b, c}},d] → [{a, c}, {a, {b, c}},d] (Huijbregts 2019)

{a, c}



Countercyclic Merge

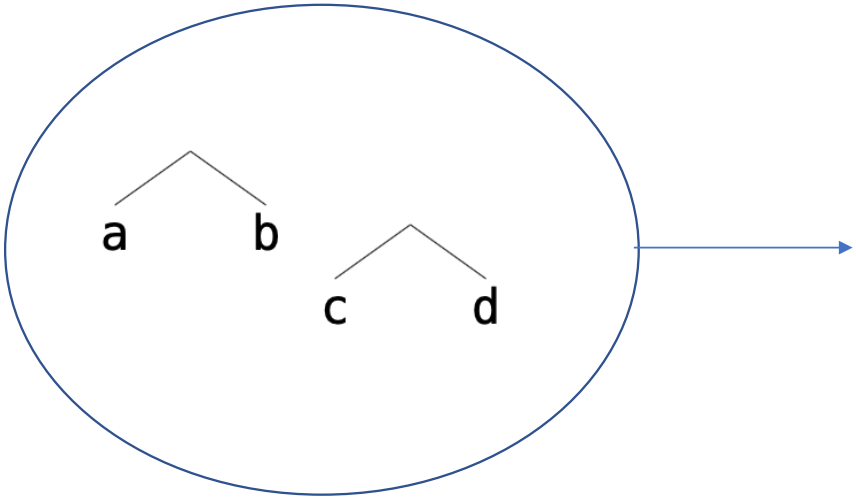


Sideward Movement

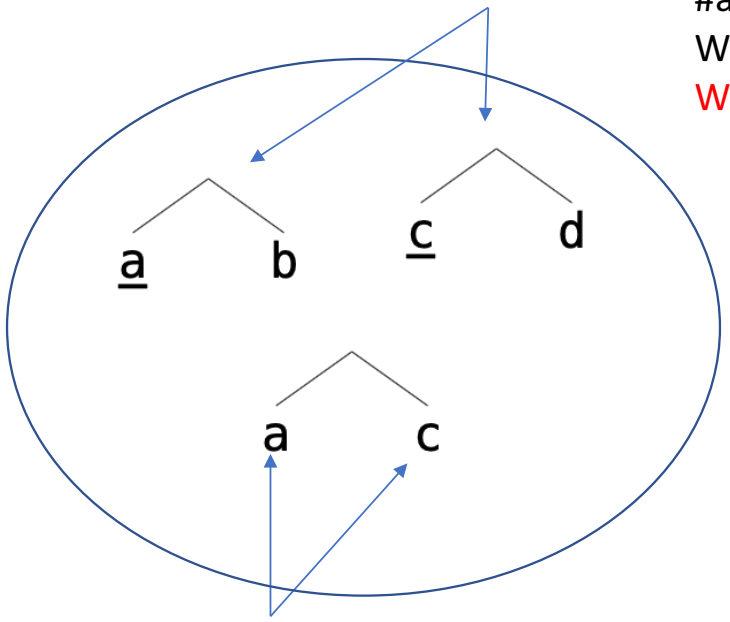
[{a,b}, {c,d}] —> [{a,c},{a,b}, {c,d}] (Huijbregts 2019)

- Not sure if examples like this exist, but they still need to be blocked.

#SOs = 2
acc. terms = 4
WS Size = 6



not accessible



#acc. terms = 2

#SOs = 3
#acc. terms = 2
WS Size = #SOs + #Acc.
WS Size = 5

WS Size decreases
This isn't allowed

Sideward Movement

- Relative Clause adjunction (following Nunes 2001)
- Which claim that John made was he willing to discuss? (Chomsky 1993: 36, Nunes 2001:316)

[{a, b}, c, d] → [{a, c}, {a, b}, d] (Huijbregts 2019)

{a, b}

$[_{CP}$ was he willing to discuss [which claim]$_1$]

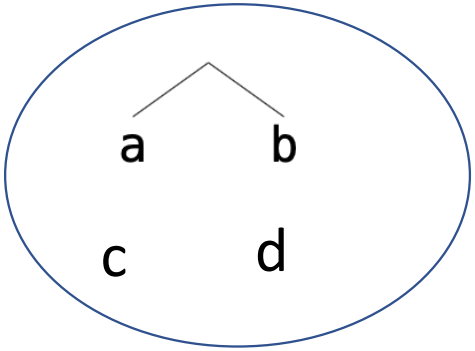
{a, c}

$[_{CP}$ [which claim]$_1$ [OP$_2$ that John made ~~Op$_2$~~]]

Workspace Right-Sizing

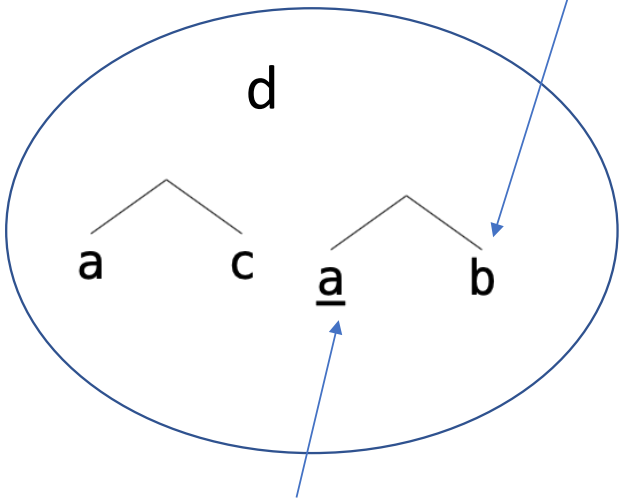
- Sideward Merge

#SOs = 3
acc. terms = 2
WS Size = 5



#SOs = 3
acc. terms = 2
WS Size = 5

Not accessible because it is an SO



not accessible

Give Example phrase

WS Size remains the same
Similar to IM

- Note that this may be a problem
- The WS Size doesn't decrease.
- This is a problem if we want to ban sideward movement

Conclusion

- Unconstrained Simplest Merge leads to an undesirable combinatorial explosion in the number of possible Syntactic Objects.
- **Research Question**: what are the well-motivated constraints that don't involve new machinery (a problem for evolution)?
- **Possible Answer**: there is no new machinery, only the simplest possible bound on WS Size, i.e., WS Size must not decrease and WS Size must not expand by more than 1.

Further consequences (*not discussed here*):

- Can replace other constraints such as on vacuous movement (e.g. iterated IM) – now can be blocked by WS Size narrow limits – normally would require loop detection machinery.
- Can also explain why language cannot count despite the free availability of IM, i.e. the successor function is simply a loop

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