# Formalizing argument structures with Combinatory Categorial Grammar

Shinnosuke Isono Takuya Hasegawa Kohei Kajikawa
Koichi Kono Shiho Nakamura Yohei Oseki

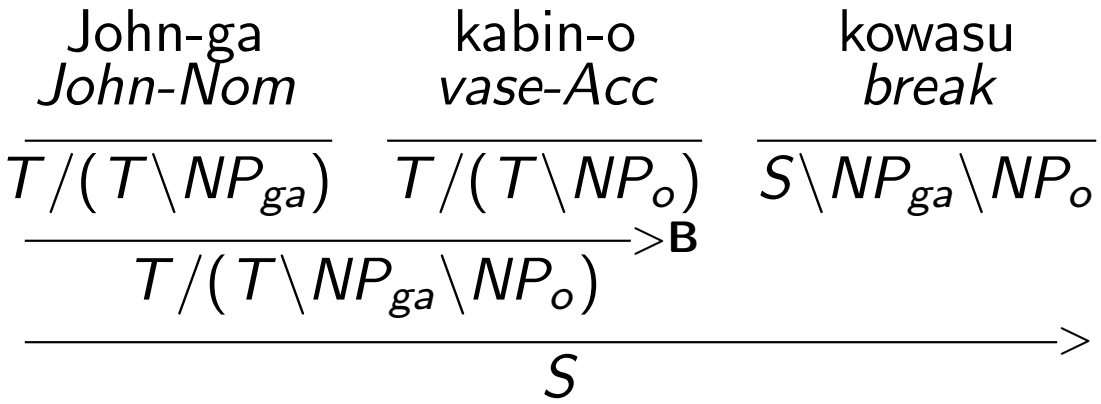
University of Tokyo

November 19, 2022 @LENLS19

# Table of contents

# Combinatory Categorial Grammar (CCG)

- A highly lexicalized theory of grammar that views syntactic derivation as directed type inference (Steedman, 2000)
- Performance-compatible
  - Allows (largely) left-to-right structure building
  - Conforms to the Strict Competence Hypothesis
    (cf. Bresnan & Kaplan, 1982)

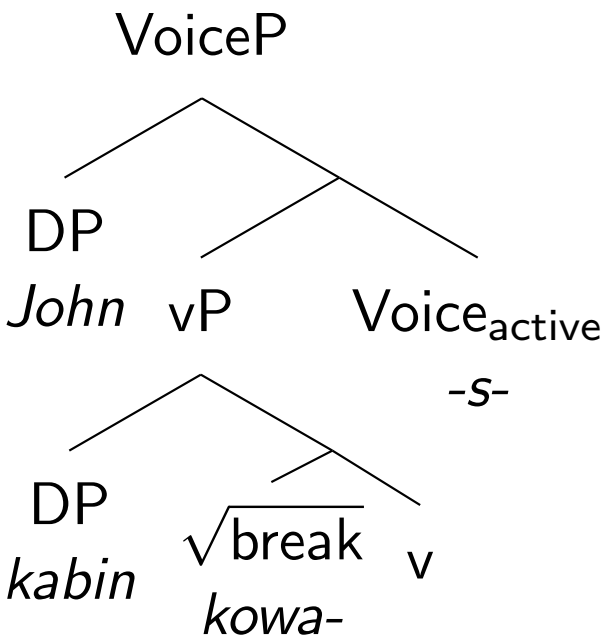



(based on Bekki, 2010)

# Where is argument structure?

- In typical CCG analyses: encoded in the verb's lexical entry
  - *kowasu*: $S\backslash NP\backslash NP$
- This resembles the "projectionist" analysis in Chomskyan generative grammar (e.g., Chomsky, 1981)
  - *kowasu*: ⟨Agent, Patient⟩
- An alternative: the "**constructivist**" analysis (Borer, 2005a, 2005b; Harley, 2014; Marantz, 2013b)

# Constructivist analysis of argument structure




(based on Oseki, 2017)

- Verb = root and functional heads
- The root does not have arguments
- Arguments are introduced by functional heads

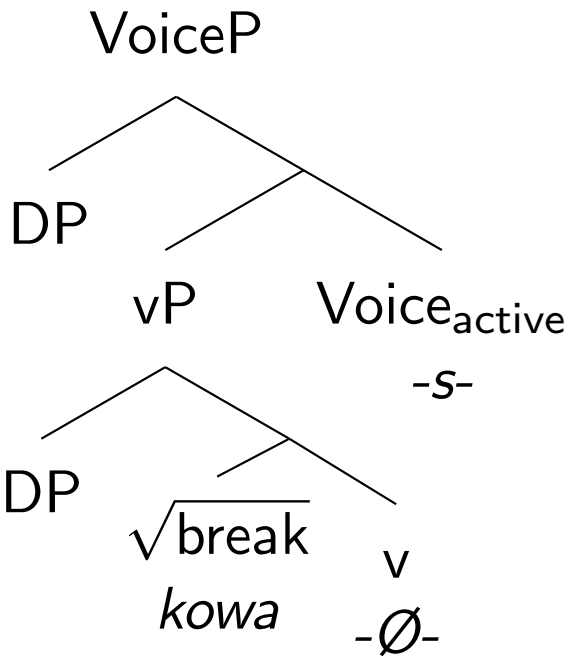
# Facts in support of constructivism

- Availability of novel argument structures (Borer, 2005a)
  - The factory horns **sirened** throughout the raid.
  - The factory horns **sirened** midday and everyone broke for lunch.
  - The police car **sirened** the Porsche to a stop.
  - The police car **sirened** up to the accident site.
  - The police car **sirened** the daylight out of me. (Clark & Clark, 1979)
- Systematic correspondence between syntactic positions and thematic roles
  - cf. UTAH (Baker, 1988)

# Distributed Morphology

- Constructivism is often couched in terms of Distributed Morphology (Halle & Marantz, 1993), based on Minimalism (Chomsky, 1995)
- Bottom-up structure building + "late insertion"

**Narrow syntax**




**Insertion rules**

$$\begin{aligned}
\sqrt{break} &\leftrightarrow \textit{kowa-} \\
v &\leftrightarrow \textit{-m-}/\sqrt{deep},\ldots \\
&\vdots \\
&\leftrightarrow \text{-Ø- (elsewhere)} \\
\text{Voice}_{active} &\leftrightarrow \textit{-s-}/\sqrt{break},\ldots \\
&\leftrightarrow \textit{-as-}/\sqrt{melt},\ldots \\
&\leftrightarrow \textit{-e-}/\sqrt{open},\ldots \\
&\vdots
\end{aligned}$$

# Bottom-up structure building?

- Bottom-up structure building and late insertion is problematic when performance is taken into account (cf. Kamide et al., 2003; Tanenhaus et al., 1995)
- Verb-argument separation matters for performance (Friedmann et al., 2008; Momma et al., 2017)

$\Rightarrow$ Can constructivist analysis be formalized in CCG?

# Table of contents

# Japanese verb conjugation paradigm

| Form | Feature | Five-grade 'fly' | Mono-grade 'see' | Irregular 'come' |
|---|---|---|---|---|
| Mizen | neg\|vo | **tob***a(nai)* | **mi***(nai)* | **k***o(nai)* |
| Ren'yoo | cont | **tob***i* | **mi** | **k***i* |
| | euph | **ton***(da)* | **mi***(ta)* | **k***i(ta)* |
| Syusi/Rentai | term\|attr | **tob***u* | **mi***ru* | **k***uru* |
| Katee | hyp | **tob***e(ba)* | **mi***re(ba)* | **k***ure(ba)* |
| Meeree | imp | **tob***e* | **mi***ro* | **k***oi* |

# Mora-based analysis (Bekki, 2010)

- It is useful for the application to corpus data, since Japanese orthography is mora-based

$$\dfrac{\dfrac{\text{to} \quad \text{ba}}{S^{v::5::b}_{neg|vo::(r|s),\pm l}\backslash S^{v::5::b}_{stem}}<\mathbf{B} \quad \text{nai}}{S^{v::5::b}_{neg|vo::(r|s),\pm l}\backslash NP_{ga}}<\mathbf{B}}{S^{a::i::NAS}_{term|attr,\pm n}\backslash NP_{ga}}$$

(based on Bekki, 2010)

# Segment-based analysis (five-grade conjugation)

$$\dfrac{\dfrac{\text{tob-} \quad \dfrac{\text{-a-}}{V_{neg|vo} \backslash V_5^{stem}} \quad \dfrac{\text{-nai}}{S_{term|attr}^{a::i::NAS} \backslash V_{neg}}}{V_5^{stem} \backslash NP_{ga}} <\mathbf{B}}{V_{neg|vo} \backslash V_5^{stem}} <\mathbf{B}$$

$$S_{term|attr}^{a::i::NAS} \backslash NP_{ga}$$

- then, *tob-* + *-ta* (past tense morpheme) = *ton-da* ??

# Segment-based analysis (five-grade conjugation)

- $Ic$ = Inflectional consonant

$$\dfrac{\dfrac{\dfrac{\text{to-} \qquad \text{-b-}}{V_5^{stem}/Ic_b\backslash NP_{ga} \qquad V_5^{stem}\backslash(V_5^{stem}/Ic_b)}<\mathbf{B}}{V_5^{stem}\backslash NP_{ga}} \qquad \text{-a-}}{V_{neg|vo}\backslash V_5^{stem} \qquad S^{a::i::NAS}_{term|attr}\backslash V_{neg}}<\mathbf{B}}{V_{neg|vo}\backslash V_5^{stem}}<\mathbf{B}}{S^{a::i::NAS}_{term|attr}\backslash NP_{ga}}<\mathbf{B}$$

# Segment-based analysis (five-grade conjugation)

- Captures phonological changes

$$\dfrac{\dfrac{\text{to-} \qquad \text{-n-}}{V_5^{stem}/Ic_b \backslash NP_{ga} \quad V_{euph::d} \backslash (V_5^{stem}/Ic_{b|m|n})}\,{<}\mathbf{B} \qquad \text{-da}}{V_{euph::d} \backslash NP_{ga} \quad S_{term|attr} \backslash V_{euph::d}}\,{<}\mathbf{B}$$
$$S_{term|attr} \backslash NP_{ga}$$

- *Ic* can also apply to the other phonological changes
  - c.f.
    - *kak-u* (write) → *kai-ta* (write-*past*)
    - *yom-u* (read) → *yon-da* (read-*past*)
    - *mawar-u* (rotate) → *mawat-ta* (rotate-*past*)
    - ...

# Segment-based analysis (mono-grade conjugation)

$$\dfrac{\dfrac{\text{mi}}{V_1^{stem}\backslash NP_{ga}\backslash NP_o} \quad \dfrac{\text{ru}}{S_{term|attr}\backslash V_1^{stem}}}{S_{term|attr}\backslash NP_{ga}\backslash NP_o}<\mathbf{B}^2$$

$$\dfrac{\dfrac{\dfrac{\text{mi}}{V_1^{stem}\backslash NP_{ga}\backslash NP_o} \quad \dfrac{\emptyset}{V_{neg|cont|euph::t}\backslash V_1^{stem}}}{V_{neg|cont|euph::t}\backslash NP_{ga}\backslash NP_o}<\mathbf{B}^2 \quad \dfrac{\text{nai}}{S^{a::i::NAS}_{term|attr}\backslash V_{neg}}}{S^{a::i::NAS}_{term|attr}\backslash NP_{ga}\backslash NP_o}<\mathbf{B}^2$$

# Segment-based analysis (irregular conjugation)

$$\dfrac{\dfrac{\text{k} \qquad \text{u}}{V_K^{stem::(term|attr)} \backslash V_K^{substem}} \qquad \text{ru}}{V_K^{stem::(term|attr)} \backslash NP_{ga}} \; <\mathbf{B} \qquad \dfrac{}{S_{term|attr} \backslash V_K^{stem::(term|attr)}}}{S_{term|attr} \backslash NP_{ga}} \; <\mathbf{B}$$

$$\dfrac{\dfrac{\text{k} \qquad \text{i}}{V_{euph::t} \backslash V_K^{substem}} \qquad \text{ta}}{V_{euph::t} \backslash NP_{ga}} \; <\mathbf{B} \qquad \dfrac{}{S_{term|attr} \backslash V_{euph::t}}}{S_{term|attr} \backslash NP_{ga}} \; <\mathbf{B}$$

# Table of contents

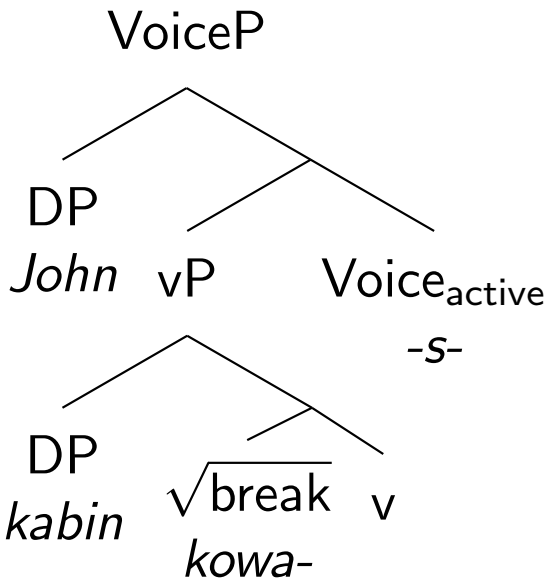
# Transitivity alternation in Japanese

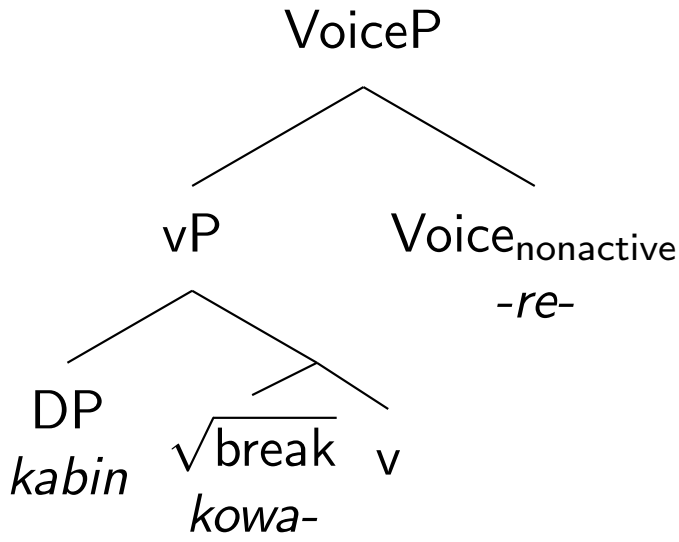
| Class | Intransitive | Transitive | Meaning |
|---|---|---|---|
| i | hag-*e*-ru | hag-Ø-u | 'peel' |
| ii | ak-Ø-u | ak-*e*-ru | 'open' |
| iii | ham-*ar*-u | ham-*e*-ru | 'fit' |
| iv | tunag-*ar*-u | tunag-Ø-u | 'connect' |
| v | ama-*r*-u | ama-*s*-u | 'remain' |
| vi | kowa-*re*-u | kowa-*s*-u | 'break' |
| vii | ka-*ri*-ru | ka-*s*-u | 'borrow/lend' |
| viii | her-Ø-u | her-*as*-u | 'decrease' |
| ix | tok-*e*-ru | tok-*as*-u | 'melt' |
| x | nob-*i*-ru | nob-*as*-u | 'extend' |
| xi | ok-*i*-ru | ok-*os*-u | 'get up' |
| xii | abi-Ø-ru | abi-*se*-ru | 'pour' |
| xiii | obi-*e*-ru | obi-*yakas*-u | 'frighten' |
| xiv | kom-*or*-u | kom-*e*-ru | 'fill' |
| xv | toraw-*are*-ru | toraw-*e*-ru | 'catch' |

(Jacobsen, 1992)

- No specific direction
- Alternation morphemes are conditioned by the root

# Analysis of the alternation in Distributed Morphology




Voice$_{active}$ $\leftrightarrow$ *-e-*/class ii,iii
$\leftrightarrow$ *-s-*/class v,vi,vii
$\leftrightarrow$ *-as-*/class viii,ix,x
$\vdots$

Voice$_{nonactive}$ $\leftrightarrow$ *-ar-*/class iii,iv
$\leftrightarrow$ *-r-*/class v
$\leftrightarrow$ *-re-*/class vi
$\vdots$

(Oseki, 2017) (also see Harley, 2008; Marantz, 2013a; Miyagawa, 1998)

# Translation to CCG

- Transitive structure (*kowa-s-u*)

$$\dfrac{\dfrac{\text{kowa-}}{\begin{array}{c}R_{vi}\\ \lambda e.kowa(e)\end{array}} \quad \dfrac{\text{-Ø-}}{\begin{array}{c}V_{base::[1]}\backslash NP\backslash R_{[1]}\\ \lambda P.\lambda x.\lambda e.P(e)\wedge theme(x)(e)\end{array}} \quad \dfrac{\text{-s-}}{\begin{array}{c}V^{stem}_{5::s}\backslash NP\backslash V_{base::(v|vi|vii)}\\ \lambda P.\lambda x.\lambda e.P(e)\wedge causer(x)(e)\end{array}}}{\begin{array}{c}V_{base::vi}\backslash NP\\ \lambda x.\lambda e.kowa(e)\wedge theme(x)(e)\end{array}}<$$

$$\dfrac{}{\begin{array}{c}V^{stem}_{5::s}\backslash NP\backslash NP\\ \lambda x.\lambda y.\lambda e.kowa(e)\wedge theme(x)(e)\wedge causer(y)(e)\end{array}}<\mathbf{B}$$

# Translation to CCG

- Intransitive structure (*kowa-re-ru*)

$$\dfrac{\dfrac{\text{kowa-}}{\begin{array}{c}R_{vi}\\ \lambda e.kowa(e)\end{array}} \quad \dfrac{\text{-Ø-}}{\begin{array}{c}V_{base::[1]}\backslash NP\backslash R_{[1]}\\ \lambda P.\lambda x.\lambda e.P(e)\wedge theme(x)(e)\end{array}} \quad \dfrac{\text{-re-}}{\begin{array}{c}V_1^{stem}\backslash V_{base::vi}\\ \lambda P.\lambda e.P(e)\end{array}}}{\begin{array}{c}V_{base::vi}\backslash NP\\ \lambda x.\lambda e.kowa(e)\wedge theme(x)(e)\end{array}}<\quad}{\begin{array}{c}V_1^{stem}\backslash NP\\ \lambda x.\lambda e.kowa(e)\wedge theme(x)(e)\end{array}}<\mathbf{B}$$

# Allomorphy by selection

- Allomorphs cannot be inserted 'late' in the current approach

→ Selection of an appropriate (Saussurean) morpheme by features

- Lexical items with the same denotations:

$$\text{-s-} \vdash V^{stem}_{5::s} \backslash NP \backslash V_{base::(v|vi|vii)} : \lambda P.\lambda x.\lambda e.P(e) \wedge causer(x)(e)$$

$$\text{-as-} \vdash V^{stem}_{5::s} \backslash NP \backslash V_{base::(vii|ix|x)} : \lambda P.\lambda x.\lambda e.P(e) \wedge causer(x)(e)$$

$$\text{-os-} \vdash V^{stem}_{5::s} \backslash NP \backslash V_{base::xi} : \lambda P.\lambda x.\lambda e.P(e) \wedge causer(x)(e)$$

$$\vdots$$

# Locality of selection / contextual allomorphy

- Wouldn't feature inheritance be problematic for:

**Locality constraints on contextual allomorphy in DM**

"only material within a spell-out domain defined by phase heads could be visible as context for VI [Vocabulary Insertion]" (Marantz, 2013a, p.96)

e.g., Verbs formed by Adj-*m*- show all the same alternation pattern

| Intransitive | Transitive | Meaning |
|---|---|---|
| huka-m-*ar*-u | huka-m-*e*-ru | 'deep-en' |
| tuyo-m-*ar*-u | tuyo-m-*e*-ru | 'strength-en' |
| taka-m-*ar*-u | taka-m-*e*-ru | 'height-en' |

- Feature inheritance, if unrestricted, would allow contextual sensitivity with absurdly long distance...

# Restricting feature inheritance for locality

- Solution: Features must be morphologically or semantically motivated
  - cf. Principle of Categorial Type Transparency (Steedman, 2000): Categories must be semantically motivated

## The Principle of Categorial Type Transparency, revised

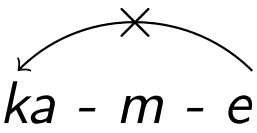
For any fragment of derivation,

- the semantic type of the interpretation,
- the morphological class of the entire string, and
- a number of language-specific directional parameter settings

uniquely determine the syntactic category of the entire tree.

inheritance allowed


inheritance blocked



# Table of contents

# Summary

- We proposed a formalization of the constructivist analysis of argument structure in CCG, which provides:
  - a basis for models of argument structure processing
  - a principled explanation for the locality of contextual allomorphy based on the locality of selection

# Further topic

- How to constrain argument structures that can be combined with a root? (suggested by the reviewers)
  - Annotate roots with features, e.g., *ker-* 'kick' as $R_{+tr}$
  - Isn't that just a 'notational variant' of $S\backslash NP\backslash NP$?

  cf. Nominalization such as *tabe-kata* 'the manner of eating'

# References I


Baker, M. C. (1988). *Incorporation: A theory of grammatical function changing*. University of Chicago Press.

Bekki, D. (2010). *Nihongo bunpoo no keisiki riron [Formal theory of Japanese grammar]*. Kurosio.

Borer, H. (2005a). *In name only*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199263905.001.0001

Borer, H. (2005b). *The normal course of events*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199263929.001.0001

Bresnan, J., & Kaplan, R. (1982). Introduction: Grammars as mental representations of language. In J. Bresnan (Ed.), *The mental representation of grammatical relations* (pp. i–lii). MIT Press.

Chomsky, N. (1981). *Lectures on government and binding*. Foris.

Chomsky, N. (1995). *The Minimalist Program*. MIT Press. https://doi.org/10.7551/mitpress/9780262527347.001.0001

Clark, E. V., & Clark, H. H. (1979). When nouns surface as verbs. *Language*, *55*(4), 767–811. https://doi.org/10.2307/412745

# References II


Friedmann, N., Taranto, G., Shapiro, L. P., & Swinney, D. (2008). The leaf fell (the leaf): The online processing of unaccusatives. *Linguistic Inquiry*, *39*(3), 355–377. https://doi.org/10.1162/ling.2008.39.3.355

Halle, M., & Marantz, A. (1993). Distributed morphology and the pieces of inflection. In K. Hale & S. J. Keyser (Eds.), *The view from Building 20: Essays in linguistics in honor of Sylvain Bromberger* (pp. 111–176). MIT Press.

Harley, H. (2008). On the causative construction. In S. Miyagawa & M. Saito (Eds.), *The Oxford handbook of Japanese linguistics* (pp. 20–53). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195307344.013.0002

Harley, H. (2014). On the identity of roots. *Theoretical Linguistics*, *40*(3–4), 225–276. https://doi.org/10.1515/tl-2014-0010

Jacobsen, W. (1992). *The transitive structure of events in Japanese*. Kurosio.

Kamide, Y., Altmann, G. T. M., & Haywood, S. L. (2003). Prediction and thematic information in incremental sentence processing. *Journal of Memory and Language*, *49*, 133–156. https://doi.org/10.1016/S0749-596X(03)00023-8

# References III


Marantz, A. (2013a). Locality domains for contextual allomorphy across the interfaces. In O. Matushansky & A. Marantz (Eds.), *Distributed morphology today: Morphemes for Morris Halle* (pp. 95–115). The MIT Press.

Marantz, A. (2013b). Verbal argument structure: Event and participants. *Lingua*, *130*, 152–168. https://doi.org/10.1016/j.lingua.2012.10.012

Miyagawa, S. (1998). *(S)ase* as an elsewhere causative and the syntactic nature of words. *Journal of Japanese Linguistics*, *16*, 67–110. https://doi.org/10.1515/jjl-1998-0105

Momma, S., Slevc, L. R., & Phillips, C. (2017). Unaccusativity in sentence production. *Linguistic Inquiry*, *49*(1), 181–194. https://doi.org/10.1162/ling_a_00271

Oseki, Y. (2017). *Voice morphology in Japanese argument structures* [submitted manuscript]. https://ling.auf.net/lingbuzz/003374

Steedman, M. (2000). *The syntactic process*. MIT Press.

# References IV

Tanenhaus, M. K., Spivey-Knowlton, M. J., Eberhard, K. M., & Sedivy, J. C. (1995). Integration of visual and linguistic information in spoken language comprehension. *Science*, *268*(5217), 1632–1634. https://doi.org/10.1126/science.7777863

# Table of contents

# Allomorphy by selection

- Allomorphs cannot be inserted 'late' in the current approach

→ Selection of an appropriate (Saussurean) morpheme by feature

- Lexical items with the same denotations can be succinctly formulated as: (cf. Bekki, 2010)

$$\forall c \in \mathrm{dom}(f)$$
$$[f(c) \vdash V^{stem} \backslash NP \backslash V_{base::c} : \lambda P.\lambda x.\lambda e.P(e) \wedge causer(x)(e)]$$

$$\text{where } f(c) \stackrel{def}{=} \begin{cases} \text{-s-} & (c = v, vi, vii) \\ \text{-as-} & (c = viii, ix, x) \\ \text{-os-} & (c = xi) \\ \vdots & \end{cases}$$

→ The same level of abstraction as DM is achieved

# Feature inheritance

- Classification of the root $R$ is inherited to [root + $v$] by a variable so that it can be selected by the Voice
- Feature inheritance by variable is necessary anyway

$$\dfrac{\dfrac{\text{John}\quad \overline{NP} \qquad \dfrac{\text{smiles}\quad \overline{S\backslash NP_{3s}} \qquad \dfrac{\text{warmly}\quad \overline{(S\backslash NP)_{[1]}\backslash(S\backslash NP)_{[1]}}}{}<}{S\backslash NP_{3s}}}{}<}{S}$$