Scuola Normale Superiore Pisa

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REAL-TIME PROCESSING OF COMPLEX SENTENCES

Outline

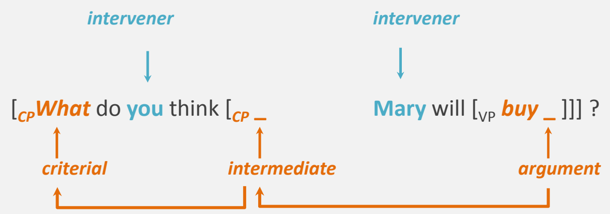
- Kinds of **non-local dependencies** causing difficulties
  - *Wh-* (long) extractions
  - Object (Restrictive) Relative Clause and Cleft
- Measuring **complexity**
  - Processing evidence
  - Memory-load accounts, similarity-based interference and featural relativized minimality
- A proposal: **cue-based memory retrieval** in **minimalist derivation**
  - Feature Retrieval Cost (**FRC**) as a prominent component of a complexity function
  - Object Clefts derivation
  - Morphosyntactic features involved

Theoretical questions

- Looking for a grammatical theory that is **explanatory adequate**
  - It should capture any known grammatical constraint in a graded way (off-line grammaticality judgments)
  - It should predict processing effects (on-line phenomena)
- Focus on non-local dependencies (**A' dependencies**)
  - How non-local dependencies are computed on-line?
  - Which features shall we consider?
  - how/when they enter the computation?

Kinds of non-local dependencies

Long distance *Wh-* dependencies



Kinds of non-local dependencies
Object Clefts

- In **Object Clefts** (**OCs**), the **copula** selects a truncated CP (Belletti 2008):

It is $[_{FocP}$ ***an ice cream*** that $[_{TP}$ ***Mary*** will ***buy*** _]]

… BE $[_{CP}$ ~~Force~~ $[_{FocP}$ … $[_{FinP}$ that $[_{TP}$ ***Subject*** … ***Object***]]]]

Kinds of non-local dependencies
Object Relatives

- In **Object Relatives** (**ORs**), the **NP** is restricted by a **RC** (see Bianchi 2001 for the peculiarities of **raising** vs **matching** analysis):

the **ice cream** $[_{CP}$ _ that $[_{TP}$ ***Mary*** will ***buy*** _]]

… ***NP$_i$*** $[_{CP}$ ***e$_i$*** that … $[_{TP}$ ***Subject*** … ***Object***]]]

… ***D*** $[_{CP}$ ***NP$_i$*** that … $[_{TP}$ ***Subject*** … ***Object***]]]

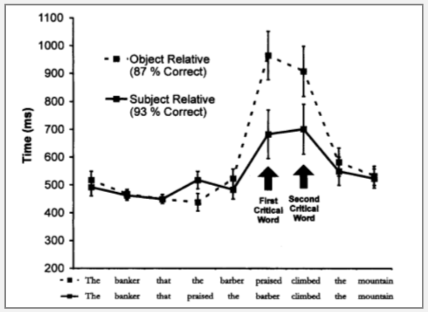
Measuring complexity
ORs processing evidence

- Gordon et al. (2001)
  working memory request is evaluated by studying **reading time** (**RT**) and **comprehension accuracy** in self-paced reading experiments comparing critical regions of various kinds of **Relative Clauses**:

- **Experiment 1** (materials): **SRs** (a) and **ORs** (b)
  - **a.** **The banker** [that _ praised **the barber**] climbed the mountain
  - **b.** **The banker** [that **the barber** praised _] climbed the mountain

Measuring complexity
ORs processing evidence

- Gordon et al. (2001) - **Experiment 1** (results)



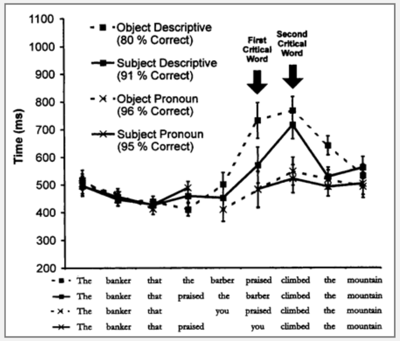
Measuring complexity
ORs processing evidence

- Gordon et al. (2001) - **Experiment 2**
  complexity can be mitigated by varying the RC **Subject typology** (**reading time** (**RT**) and **comprehension accuracy** in self-paced reading experiments are tested, as before):

- **Experiment 2** (materials): **DP** (a) vs. **Pro** (b)
  a. **The banker** [that **the barber** praised _] climbed the mountain
  b. **The banker** [that **you** praised _] climbed the mountain

Measuring complexity
ORs processing evidence

- Gordon et al. (2001) - **Experiment 2** (results)



Measuring complexity
ORs processing evidence

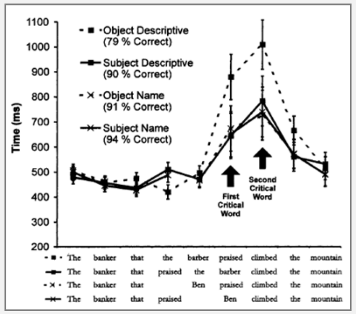
- Gordon et al. (2001) - **Experiment 3** (materials):

DP (a) vs. **proper nouns** (b)

a. **The banker** [that **the barber** praised _] climbed the mountain
b. **The banker** [that **Ben** praised _] climbed the mountain

Measuring complexity
ORs processing evidence

- Gordon et al. (2001) - **Experiment 3** (results)



Measuring complexity
OCs processing evidence

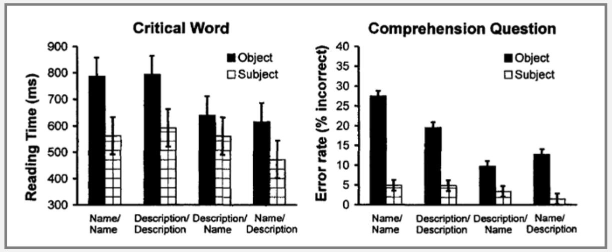
- Gordon et al. (2001) - **Experiment 4** (materials):

Subject vs. Object Clefts X **DP** vs. **proper names**

a. It was **the banker** that **the lawyer** **saw** _ in the parking lot
b. It was **the banker** that **Bill** **saw** _ in the parking lot
c. It was **John** that **the lawyer** **saw** _ in the parking lot
d. It was **John** that **Bill** **saw** _ in the parking lot

Measuring complexity
OCs processing evidence

- Gordon et al. (2001) - **Experiment 4** (results):



Measuring complexity
tentative accounts

- **Role-determinant** accounts (MacWhinney & Pleh 1988)
  - **Double role** for the RC head: **subject** in the matrix sentence, **object** in the RC:
    The banker [that the barber **praised** _] **climbed** the mountain (OR)

- **Memory-load** accounts (Ford 1983, MacWhinney 1987, Wanner & Maratsos 1978 …)
  - The RC head must be **kept in memory longer** in OR before being integrated:
    The banker [that **praised** the barber] climbed … (SR)
    The banker [that **the barber** **praised** _] climbed … (OR)

Measuring complexity
tentative accounts

- **Linguistic Integration Cost** (Gibson 1998:12-13)
  - Processing difficulty is proportional to the distance expressed in terms of number of **intervening discourse referents**, following a "referentiality hierarchy":
    descriptions > (**short**) **names** >
    referential pronouns > **indexical pronouns**

- **Similarity based accounts** (Gordon et al. 2001)
  - Having **two DPs of the same kind** stored in **memory** makes the OR more complex than SR. This models **memory interference** during encoding, storage and retrieval (Crowder 1976)

Measuring complexity
tentative accounts

- More on **Similarity based accounts** (Gordon et al. 2001)
  - It might be able to explain why **SR** vs. **OR** asymmetry disappears with RC subject **pro/proper names** (those DPs are legal heads only for clefts)
- **Intervention effects** (Grillo 2008, Friedmann et al. 2009, Rizzi 1990)
  - Processing difficulty is **proportional** to the number and kind of relevant features shared between the moved item and any possible intervener:

X *Z* *Y*

Measuring complexity
intervention-based account

- More on **Intervention effects** (Friedmann et al. 2009)
  - **Identity** (**bad** for adults, **bad** for children)

    +A *+A* *(+A)*
  - **Inclusion** (**ok** for adults, **bad** for children)

    +A +B *+A* *(+A +B)*
  - **Disjunction** (**ok** for adults, **ok** for children)

    +A *+B* *(+A)*

Measuring complexity
Comparing features in OCs

- Warren & Gibson (2005) - **Experiment** (materials):
  definite descriptions vs. **proper names** vs. **pronouns**

a. It was **the banker** that **the lawyer** **avoided** _ at the party
b. It was **the banker** that **Dan** **avoided** _ at the party
c. It was **the banker** that **we** **avoided** _ at the party
d. It was **Patricia** that **the lawyer** **avoided** _ at the party
e. It was **Patricia** that **Dan** **avoided** _ at the party
f. It was **Patricia** that **we** **avoided** _ at the party
g. It was **you** that **the lawyer** **avoided** _ at the party
h. It was **you** that **Dan** **avoided** _ at the party
i. It was **you** that **we** **avoided** _ at the party

Measuring complexity
Comparing features in OCs

- Warren & Gibson (2005) - **results** (Tessa Warren P.C.)
  D = definite description (e.g. **the banker**)
  N = proper names (e.g. **Dan**)
  P = pronouns (e.g. **you**)

condition	D-D	D-N	D-P	N-D	N-N	N-P	P-D	P-N	P-P
Read. time (SE) ms	365 (19)	319 (12)	306 (14)	348 (18)	347 (21)	291 (14)	348 (18)	311 (15)	291 (13)

Measuring complexity
Comparing features in OCs

- Assuming that **Definite Description** = {**+NP**, **N**}, **Proper Names** = {**+NP**, N_{Proper}}, **pro** = {} (Belletti & Rizzi 2013),
  Intervention effects are predicted to be stronger in matching **D-D** and **N-N** condition (against memory-load accounts), while **P-P** is expected not to be critical (because of the **+NP** absence):

condition	D-D	D-N	D-P	N-D	N-N	N-P	P-D	P-N	P-P
Read. time (SE) ms	**365** (19)	**319** (12)	**306** (14)	**348** (18)	**347** (21)	**291** (14)	**348** (18)	**311** (15)	**291** (13)
prediction	hard	?	easy	?	hard	easy	easy	easy	easy

Measuring complexity
which features are relevant

- Features triggering movement are those relevant for intervention (Friedmann et al. 2009:82), but:
  - "**+R**" feature causing Object movement in ORs (or "**+Foc**" in OCs) is not present on Subject;
  - Neither the "**lexical restriction**" nor **phi-features** trigger any movement in **ORs** or **OCs**
  - The "**lexical restriction**" should be not accessible at the **edge of the DP**, where features triggering movement should be located (but see Belletti & Rizzi 2013, next slide)
  - Why slow-down is observed at **verb segment**?

Measuring complexity
lexical restriction is considered

- Belletti & Rizzi 2013:
  - Evidence that lexically restricted wh-items occupy different positions in the left periphery (Munaro 1999):

a. Con **che tosat** à-tu parlà?
with which boy did you speak?

b. Avé-o parlà de **chi**?
Have you spoken of whom?

Measuring complexity
a summary

- An "integration cost" (cf. Gibson 1998) is not enough
  - È **il bambino** che **il signore** ha salutato …
  - È **Luigi** che **Gianni** ha salutato …

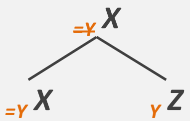
- **Intervention-based accounts** are not "**gradable**" (no quantitative, precise measurements)

- **Bottom-Up** standard theories **do not make any clear predictions on processing**: they predict what creates complexity, but not **when**, **why** and **how** exactly in **parsing** and **generation**?

A processing friendly proposal

Phase-based Minimalist Grammar (Chesi 2015)

- Common restriction on **Merge**:
  - Given two lexical items [$_{=Y}$ *X*] and [$_{Y}$ *Z*] such that *X* selects *Z*, then:

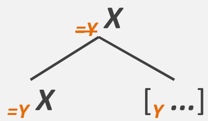


  - [$_{=Y}$ *X*] is processed before *Y*
  - When [$_{=Y}$ *X*] is processed, **an expectation** for [$_{Y}$ ...] is created

A processing friendly proposal

Phase-based Minimalist Grammar (Chesi 2015)

- A **Phase** is the minimal computational domains within which a selection requirement must be satisfied:
  - Given a lexical item [$_{=Y}$ *X*], [$_{Y}$ ...] is the **selected phase**:

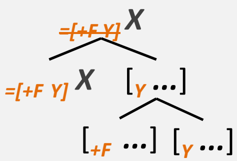


  - **Merge** reduces to **lexical selection** (or **unification**) (e.g. [$_{Y}$ *Z*] insertion)

A processing friendly proposal

Phase-based Minimalist Grammar (Chesi 2015)

- If we assume that selection can include both functional features (*+F*) and lexical features (*Y*) at the same time, a **Phase** becomes a subtree to be expanded:
  - Given a lexical item [$_{=[+F\ Y]}$ *X*], [$_{+F\ Y}$ ...] is the **selected phase**:

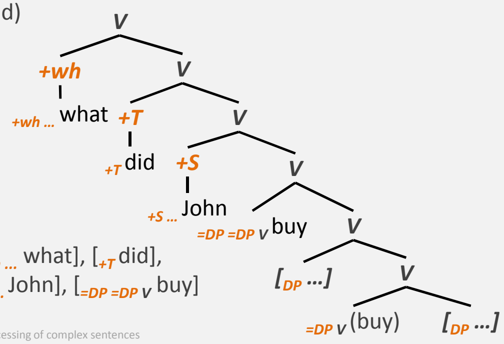


  - [*+F Y* ...] is an **extended projection** of a **lexical category** *Y* (e.g. a **DP** is an extended projection of **N**, i.e. [**+D N**])

A processing friendly proposal

Phase-based Minimalist Grammar (Chesi 2015)

- Both a declarative sentence [*+S +T V*] and a ***wh-*** question [*+wh +T +S V*] are phases (i.e. extended projections of a V head)

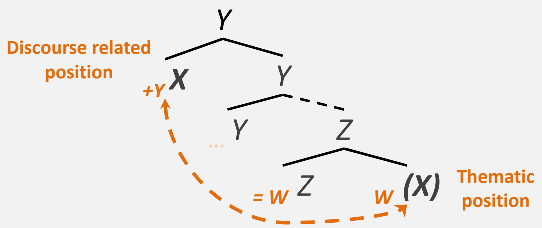


- [$_{+wh\ ...}$ what], [$_{+T}$ did], [$_{+S\ ...}$ John], [$_{=DP\ =DP\ V}$ buy]

A processing friendly proposal

Phase-based Minimalist Grammar (Chesi 2015)

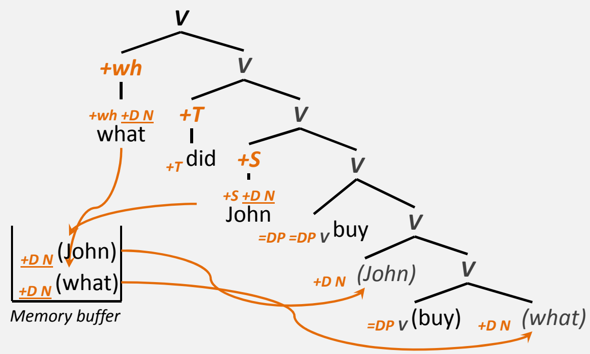
- Common trigger for **Move**:
  - An item [$_{+Y \ldots W}$ *X*], in a given structure, must be moved if it can not be **fully interpreted** in its insertion position:



A processing friendly proposal

Phase-based Minimalist Grammar (Chesi 2015)

- [$_{+wh\ +D\ N}$ what], [$_{+T}$ did], [$_{+S\ +D\ N}$ John], [$_{=DP\ =DP\ V}$ buy]



A processing friendly proposal

Phase-based Minimalist Grammar (Chesi 2015)

- The derivation unfolds **Top-Down** and **Left-Right**
- **Unexpected features** trigger movement
- **Phases** restrict the domain in which a non-local dependency must be satisfied
- **Last-In-First-Out memory buffer**, as a first approximation, is used to store and retrieve items for non-local dependencies (memory buffer must be **empty** at the end of the derivation)

A processing friendly proposal

Deriving OCs (Top-Down) using PMGs

- In Object Clefts (OCs), the copula selects a truncated CP (Belletti 2008):

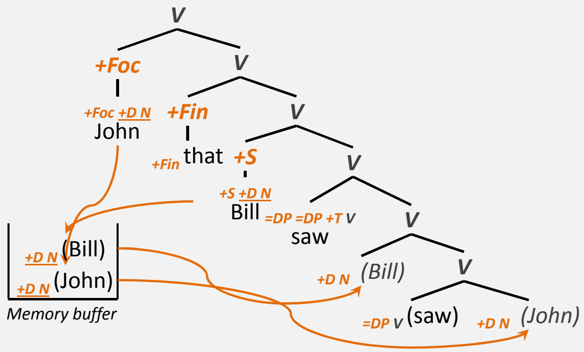
  … BE [$_{CP}$ ~~Force~~ [$_{FocP}$ … [$_{FinP}$ that [$_{TP}$ *Subject* … ***Object***]]]]

- Reduced CP (CP$_r$) = [+Foc +Fin +S +T V]

A processing friendly proposal

Deriving OCs (Top-Down) using PMGs

- It [... =CPr ... was] [$_{CPr}$ **John** that **Bill saw**]



A processing friendly proposal

On complexity: cue-based retrieval and intervention

- **interference** is the major constraint on accessing information in memory (Anderson & Neely 1996; Crowder 1976; see Nairne 2002 for a review).
- the locus of the interference effect is at **retrieval**, with **little or no effect** on memory **encoding** or **storage** (Dillon & Bittner 1975; Gardiner et al. 1972; Tehan & Humphreys 1996)
- **Content-adressable memory** (e.g. **memory load paradigm**, Van Dyke & McElree 2006), no **exhaustive search**, no **delay**
- **Search of Associative Memory** (**SAM**) model (Gillund & Shiffrin 1984)

$$P(I_i/Q_1, \ldots, Q_n) = \frac{\prod_{j=1}^{m} S(Q_j, I_i)^{w_j}}{\sum_{k=1}^{N} \prod_{j=1}^{m} S(Q_j, I_k)^{w_j}}$$

A processing friendly proposal

On DP features (and structure)

- Both **proper** and **common nouns** have a category **N**

N in situ (common nouns)	***N-to-D raising***
Il mio Gianni (Il mio amico) *the my G.*	*mio Gianni *my G.*
La sola Maria (la sola amica) *the only M.*	Maria sola (*l'amica sola) *M. only*

- But two different kinds of **N**: $\mathbf{N}_{proper}$, $\mathbf{N}_{(common)}$

A processing friendly proposal

On DP features (and structure)

- Longobardi (1994-2005), a (rough) summary:
  - **Definite Descriptions** [$_D$ the [$_N$ man]]
  - **Proper Nouns** [$_D$ John$_i$ [$_N$ t_i]]
  - **Pronouns** [$_D$ you [$_N$ ∅]]

- Elbourne (2005)
  [[THE *i*] **NP**]

A processing friendly proposal

On DP features (and structure)

- Both **determiners** and **personal pronouns** introduce a "referential pointer" to an individual constant or variable in the domain of discourse
- Pro are NP-ellipsis licensors (they can be used as determiners «we italians»): $[_D$ noi $[_N$ ~~italiani~~]]
(**D** introduces an *index*, that bounds a variable predicated in N)
- (More) features on **pro**:
  - **1st** and **2nd** person (highly accessible referents) vs. **3rd** person (**default person**, context-determined referent)
  - **case**

A processing friendly proposal

On DP features (and structure)

- **Definite descriptions**: **{+D, +num, N}**
- **Proper nouns**: **{+D, +num, N_{prop}}**
- **Pronouns**: **{+D, +case, +pers, +num}**

Feature Retrieval Cost (FRC) metrics at work

- Cost function (at ***X*** given $\boldsymbol{m_x}$ items to be retrieved from memory)

$$C_{FRC}(x) = \prod_{i=1}^{m_x} \frac{(1+nF_i)^{m_i}}{(1+dF_i)}$$

  - *m* = number of items stored in memory at retrieval
  - *nF* = number of features characterizing the argument to be retrieved that are non-distinct in memory (i.e. also present in other objects in memory)
  - *dF* = number of distinct cued features (e.g. agreement and case features probed by the verb)

Feature Retrieval Cost (FRC) metrics at work

$$C_{FRC}(x) = \prod_{i=1}^{m_x} \frac{(1+nF_i)^{m_i}}{(1+dF_i)}$$

- ***D-D*** matching
it was **the lawyer**$_{\{+D, +num\_sing, N\}}$ who **the businessman**$_{\{+D, +num\_sing, N\}}$ *avoided*...

C_{FRC} (***avoided***) = **16**

that is **16** · **1**:
16 for retrieving **the businessman**,
nF=3, *m*=2 (because two *D*s are in memory at that retrieval time), and
dF=0 (because no feature is cued by the verb distinguishing one *D* from the other);
1 for retrieving **the lawyer**,
since ***nF*=0**, ***m*=1** and ***dF*=0**

Feature Retrieval Cost (FRC) metrics at work

$$C_{FRC}(x) = \prod_{i=1}^{m_x} \frac{(1+nF_i)^{m_i}}{(1+dF_i)}$$

- ***N-N*** matching

  it was **Dan**$_{\{+D, +num\_sing, N\_prop\}}$ who **Patricia**$_{\{+D, +num\_sing, N\_prop\}}$ *avoided…*

  C_{FRC} **(*avoided*)** = **16**

  that is **16 · 1**:

  16 for retrieving **Dan**,

  ***nF*=3, *m*=2** (because two *D*s are in memory at that retrieval time), a nd ***dF*=0** (because no feature is cued by the verb distinguishing one *D* from the other);

  1 for retrieving **Patricia**,

  since ***nF*=0**, ***m*=1** and ***dF*=0**

Feature Retrieval Cost (FRC) metrics at work

$$C_{FRC}(x) = \prod_{i=1}^{m_x} \frac{(1+nF_i)^{m_i}}{(1+dF_i)}$$

- ***P-P*** matching

  it was **you**$_{\{+D, +pers\_II, +num\_sing, +case\}}$ who **we**$_{\{+D, +pers\_I, +num\_plur, +case\_nom\}}$ *avoided…*

  C_{FRC} **(*avoided*)** = **1**

  that is **1 · 1**:

  1 for the **we**,

  ***nF*=1**, ***m*=2** and ***dF*=1** (**number**, **person** and **case** mismatches are always present; **case** is cued by the verb),

  1 for retrieving **you**,

  ***nF*=0**, ***m*=1** and ***dF*=0** for the object pronoun

Feature Retrieval Cost (FRC) metrics at work

$$C_{FRC}(x) = \prod_{i=1}^{m_x} \frac{(1+nF_i)^{m_i}}{(1+dF_i)}$$

- ***D-N*** matching

  it was **the lawyer**$_{\{+D, +num\_sing, N\}}$ who **Patricia**$_{\{+D, +num\_sing, N\_prop\}}$ *avoided…*

  C_{FRC} **(*avoided*)** = **12,25**

  that is **12,25 · 1**:

  12,25 for **Patricia**,

  ***nF*=2.5**, ***m*=2**, ***dF*=0** (N_{prop} vs. N counts as half because of movement)

Feature Retrieval Cost (FRC) metrics at work

$$C_{FRC}(x) = \prod_{i=1}^{m_x} \frac{(1+nF_i)^{m_i}}{(1+dF_i)}$$

- ***P-D*** condition

  it was **you**$_{\{+D, +pers\_II, +num\_sing, +case\}}$ who **the businessman**$_{\{+D, +num\_sing, N\}}$ *avoided…*

  C_{FRC} **(*avoided*)** = 9

  that is **9 · 1**:

  9 for the **the businessman**,

  ***nF*=2**, ***m*=2**, ***dF*=0**

Feature Retrieval Cost (FRC) metrics at work

$$C_{FRC}(x) = \prod_{i=1}^{m_x} \frac{(1+nF_i)^{m_i}}{(1+dF_i)}$$

- ***D-P*** condition
  it was **the lawyer**$_{\{+D,\ +num\_sing,\ N\}}$ who **we**$_{\{+D,\ +pers\_I,\ +num\_plur,\ +case\_nom\}}$ *avoided...*

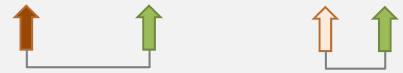
  C_{FRC} **(*avoided*)** = **4,5**

  that is **4,5** · **1**:
  4,5 for the **we**,
  nF=2, ***m=2***, ***dF=1*** (**case** is cued)

Feature Retrieval Cost (FRC) metrics at work

The complete prediction set:

condition	D-D	D-N	D-P	N-D	N-N	N-P	P-D	P-N	P-P
Read. time (SE) ms	**365** (19)	**319** (12)	**306** (14)	**348** (18)	**347** (21)	**291** (14)	**348** (18)	**311** (15)	**291** (13)
prediction	16	12,25	4,5	12,25	16	4,5	9	9	1



Feature Retrieval Cost (FRC) metrics at work

- Some potential corrections:
  - The **pro subject effect** (fastest verb reading in **D-P**, **N-P**, **P-P** conditions)
    pronominal subjects expressing **1st** and **2nd** person features create expectations (***eF***$_i$) that could facilitate verb processing (see antilocality effects, Jaeger et al. 2005);
  - The **referentiality hierarchy** makes the correct prediction most of the time (**N** is more accessible than **D**, hence at the verb segment: **N**<**D**):
    rH$_i$ = **1** for **D**, **0.5** for **N**

- $C_{FRC}(x) = \prod_{i=1}^{m_x} \frac{(1+nF_i+rH_i)^{m_i}}{(1+dF_i+eF_i)}$

Feature Retrieval Cost (FRC) metrics at work

The complete prediction set:

condition	D-D	D-N	D-P	N-D	N-N	N-P	P-D	P-N	P-P
Read. time (SE) ms	**365** (19)	**319** (12)	**306** (14)	**348** (18)	**347** (21)	**291** (14)	**348** (18)	**311** (15)	**291** (13)
new prediction	30,38	20,54	7,50	19,20	21,17	3,60	12,25	10,24	1,00
old prediction	16	12,25	4,5	12,25	16	4,5	9	9	2

A processing friendly proposal
Testing the FRC with restricted pronouns

- **Idea** (Chesi, Canal, Belletti & Rizzi – in progress)
  pronouns can be used as **determiners**, but they have more features than articles: keeping number features constant and the lexical restriction present, we can test the impact of **person** (**2nd** vs **3rd**) **features** on encoding and retrieval.

- **Materials:** 32 items (8 per condition) + 112 fillers
  - Sono/siete **gli/voi architetti** che **gli/voi ingegneri**
    are_{3P_PL}/are_{2P_PL}/ the/you architects that the/you engineers

    hanno/avete consultato _ prima di iniziare i lavori.
    $have_{3P\_PL}$/$have_{2P\_PL}$/ consulted before beginning the work

A processing friendly proposal
Testing the FRC with restricted pronouns

- **Subjects**
  33 subjects (age range = 19-35; 15 male; center-north Italian native speakers)

- **Methods**
  - **eye-tracking** experiment (Eyelink 1000, desktop, dominant eye tracking)
  - **yes/no comprehension question** (50% YES, 50% NO; 50% targeting the subject, 50% targeting the object; 50% with PP in question, 50% without)
    Item: *Sono **gli architetti** che **voi ingegneri** avete consultato _ …*
    Question: ***Gli architetti** hanno consultato qualcuno? (no!)*
  - *Verbal Working Memory Capacity (VWM)* assessment after eye-tracking experiment (sentence span, Lewandowsky et al. 2010)

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- **Regions**

| Sono | **gli architetti** | che | **voi ingegneri** | **avete consultato** | prima di iniziare |
BE DP1 C DP2 verb spill

- **Measures** (Rayner, 1998)
  - First Fixation
  - Gaze duration
  - Second pass reading time
  - Total duration
  - Regressions (from and in)

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- Statistics
  - We use **mixed-effects regression models** (Baayen, Davidson & Bates, 2008; lme4 R package, Bates, 2011).
  - **Reading times** data were analyzed by **fitting general linear mixed models** (lmer function, e.g., Baayen et al., 2008), whereas (categorical) regression data were analyzed by fitting **mixed-effects logistic regressions** (glmer, e.g., Jaeger, 2008).
  - In all analyses we tried to identify the **optimal random structure justified by the data**, starting from the maximal model and pruning the factors which showed very little variance or high correlations in the random effects covariance matrix.
  - Reading times were **log-transformed** to respect the normality assumption of mixed-effects regression models. The presence of **significant interaction was attested comparing models likelihood** with and without interaction terms.

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- **Results**: accuracy in comprehension questions

DP1	DP2	Accuracy %
art	art	75%
art	pro	81%
pro	pro	70%
pro	art	74%

- art pro > art art ≥ pro art > pro pro

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- Comparing accuracy results with an **Off-line** grammaticality judgment test:
  - **Subjects**: 48; age range: 20-64; 25 Females, 23 Males; center/north Italian native speakers
  - **Methods**: 7-point Likert scale grammaticality judgment (on-line data collection, using Osucre)
  - **Materials**: same items/filler of the eye-tracking experiment

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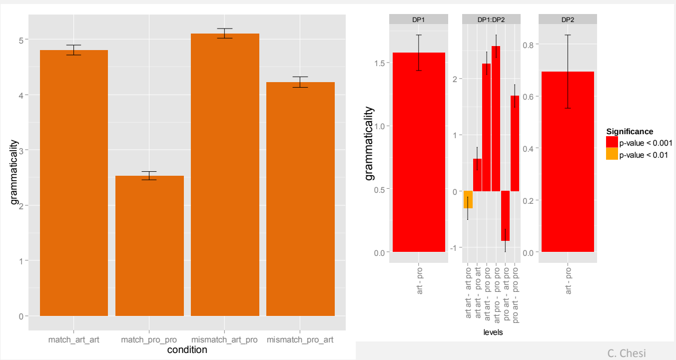
- **Results** of the **Off-line** grammaticality judgment test



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- **In sum**
- Accuracy in comprehension questions (eyetracking)
  art pro > art art ≥ pro art > pro pro
- Off-line grammaticality judgment test
  art pro > art art > pro art > pro pro

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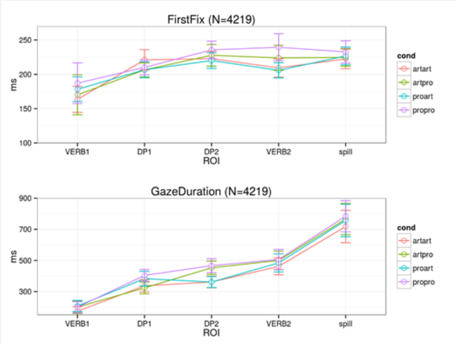
Testing the FRC with restricted pronouns

- **RESULTS**



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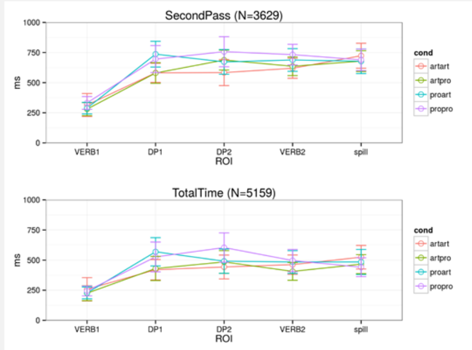
- **RESULTS**



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Testing the FRC with restricted pronouns

- **RESULTS**
- **First Fixation** (**verb** region):
  - main effect of **DP2** (-0.095, t=-4.37) (**art** is read faster than **pro**)
  - Main effect of **WM** (-0.39, t=-2.82) (**high WM faster** reading than low *WM*)
  - **interaction between WM** and **DP2** (0.33, t=2.48) suggesting that the **slow down** associated to **DP2 pro** is **mainly driven** by **low WM** participants.
  - Even tough the **interaction between DP1** and **DP2** is not very robust (comparison between the relevant models has chisq=2.16, p=0.14): **pro pro** > **art pro** > **art art** ≥ **pro art**

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- **RESULTS**
- **Gaze Duration** (**DP2** region):
  - Gaze duration is **marginally affected** by type of **DP2** (-0.066, t=-2.07).
  - The effect of **WM** is also **significant** (faster gaze for high WM: -1.10 t=4.35).
  - No further interactions resulted significant.
- **Second Pass** (**verb** region):
  - **main effect** of **DP1** (**art** speeds up re-reading **verb** compared to **pro**);
  - **DP2** X **WM interaction** and a three ways interaction suggesting a strong effect of **WM** only when **DP1** is **pro** and **DP2** is **art**: in **pro art**, **low WM** participants spend more time re-reading **verb**.

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- **RESULTS**

- **Total Time Duration**:
  - main effects are **not significant**.
  - some hints of an interaction (chisq=2.32, p=0.12) emerged when the **DP2** is art, no differences emerge as function of **DP1**, whereas when **DP2** is pro a slow down is associated when also **DP1** is pro.

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Testing the FRC with restricted pronouns

- **In sum**
  - **On-line**
    First fixation on **verb** segment
    art < **pro** (**DP2** main effect)
    pro art < **art art** < **art pro** < **pro pro** (non significant **DP1**:**DP2** interaction)
    Second Pass on **verb** segment
    DP1 x DP2 x WM **DP1** is pro and **DP2** is art: in pro art, **low WM**
    art pro ≈ **art art** < **pro art** ≈ **pro pro**
  - **Off-line**
    Accuracy in **comprehension** questions
    art pro > **art art** ≥ **pro art** > **pro pro**
    Grammaticality judgment test
    art pro > **art art** > **pro art** > **pro pro**

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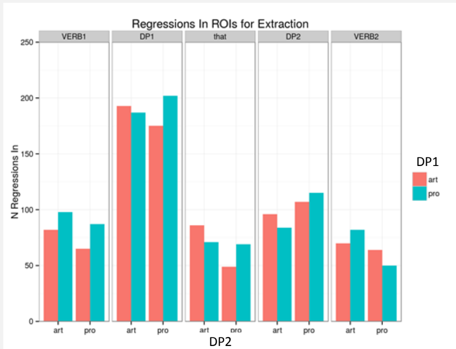
- **RESULTS**

A processing friendly proposal
Testing the FRC with restricted pronouns

- **RESULTS**



A processing friendly proposal

Testing the FRC with restricted pronouns

- **RESULTS**
  - Regressions from **DP2** : no main effects. no interactions.
  - Regressions from **VERB** : Main effect of WM : higher WM -> larger number of Regressions. no interactions.
  - Regressions in **DP1** : Main effect of WM : higher WM -> larger number of Regressions. no interactions.
  - Regressions in **DP2** : Main effect of WM : higher WM -> larger number of Regressions.

Feature Retrieval Cost (FRC) metrics at work

$$C_{FRC}(x) = \prod_{i=1}^{m_x} \frac{(1+nF_i)^{m_i}}{(1+dF_i)}$$

- ***art-art*** matching

gli architetti $_{\{+D, +num\_pl, N\}}$ che **gli ingegneri** $_{\{+D, +num\_pl, N\}}$ hanno evitato

C_{FRC} (***avoided***) = **16**

that is **16 · 1**:
16 for retrieving **gli ingegneri**,
***nF*=3**, ***m*=2**, and ***dF*=0**;
1 for retrieving **gli architetti**,
since ***nF*=3**, ***m*=1** and ***dF*=0**

Feature Retrieval Cost (FRC) metrics at work

$$C_{FRC}(x) = \prod_{i=1}^{m_x} \frac{(1+nF_i)^{m_i}}{(1+dF_i)}$$

- ***pro-pro*** matching

voi architetti $_{\{+D, +2P, +num\_pl, N\}}$ che **voi ingegneri** $_{\{+D, +2P, +num\_pl, N\}}$ avete evitato

C_{FRC} (***avoided***) = **25**

that is **25 · 1**:
36 for retrieving **gli ingegneri**,
***nF*=4**, ***m*=2**, and ***dF*=0**;
1 for retrieving **gli architetti**,
since ***nF*=0**, ***m*=1** and ***dF*=0**

Feature Retrieval Cost (FRC) metrics at work

$$C_{FRC}(x) = \prod_{i=1}^{m_x} \frac{(1+nF_i)^{m_i}}{(1+dF_i)}$$

- ***art-pro*** matching

gli architetti $_{\{+D, +num\_pl, N\}}$ che **voi ingegneri** $_{\{+D, +2P, +num\_pl, N\}}$ avete evitato

C_{FRC} (***avoided***) = **8**

that is **8 · 1**:
8 for retrieving **gli ingegneri**,
***nF*=3**, ***m*=2**, and ***dF*=1** (because **+2P** is cued by the verb);
4 for retrieving **gli architetti**,
since ***nF*=0**, ***m*=1** and ***dF*=0**

Feature Retrieval Cost (FRC) metrics at work

$$C_{FRC}(x) = \prod_{i=1}^{m_x} \frac{(1+nF_i)^{m_i}}{(1+dF_i)}$$

- *pro* - *art* mismatch
  voi architetti $_{\{+D, +2P, +num\_pl, N\}}$ che gli ingegneri $_{\{+D, +num\_pl, N\}}$ hanno evitato

  C_{FRC} (*avoided*) = 16

  that is 16 · 1:
  16 for retrieving gli ingegneri,
  nF=3, *m*=2, and *dF*=0 (because **+3P** is cued by the verb);
  1 for retrieving gli architetti,
  since *nF*=0, *m*=1 and *dF*=0

Feature Retrieval Cost (FRC) metrics at work

- **On-line**
  First fixation on **verb** segment
  art < **pro** (**DP2** main effect)
  pro art < **art art** < **art pro** < **pro pro** (non significant **DP1**:**DP2** interaction)
  Second Pass on **verb** segment
  DP1 x DP2 x WM **DP1** is **pro** and **DP2** is **art**: in **pro art**, **low WM**
  art pro ≈ **art art** < **pro art** ≈ **pro pro**
- **Off-line**
  Accuracy in **comprehension** questions
  art pro > **art art** ≈ **pro art** > **pro pro**
  Grammaticality judgment test
  art pro > **art art** > **pro art** > **pro pro**
- **FRC**
  art pro < **art art** ≈ **pro art** < **pro pro**

Conclusion

- We rephrased the intervention-based idea (Friedmann et al. 2009) in Top-Down terms, trying to reconcile the **formal account** of intervention (**what**) with **processing evidence** (**when** and **how**)
- What permits to express the exact complexity cost is a **Top-down** (that in the end produce a **left-right**) derivation (this way the model fitting can be directly compared with other complexity metrics, e.g. SPLT, Gibson 1998)
- The special role of intervention has been expressed in terms of **interference** at **retrieval** (e.g. Van Dyke & McElree 2006)

Further development

- Feature structures (and actual cues) need to be further refined (other features, e.g. **animacy**, Kidd et al. 2007, and **semantic selection**, Gordon et al. 2004, should be considered)
- The counterintuitive idea that **Subject** "is harder" to retrieve than **Object** in ORs should receive experimental support
- Is it a purely privative system (**+/- F**) enough?
- Doing away with **LIFO structure** which is computationally **OK**, but psycholinguistically odd (cf. **content-adressable memory**).

Thank you!

- **Selected References**

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