

Neglect-zero and no-split: cognitive biases at the semantic-pragmatic interface

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Free Choice Inferences: Theoretical and experimental approaches

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NØthing is logical (Nihil)



- ▶ Goal of the project: a formal account of a class of natural language inferences which deviate from classical logic
- ▶ Common assumption: these deviations are not logical mistakes, but consequence of pragmatic enrichments
- ▶ Strategy: develop *logics of conversation* which model next to literal meanings also pragmatic/cognitive factors and the additional inferences which arise from their interaction
- ▶ Novel hypothesis: **neglect-zero** tendency (and **no-split**) as crucial pragmatic/cognitive factors
- ▶ Main conclusion: deviations from classical logic consequence of pragmatic enrichments albeit not of the canonical Gricean kind



Nihil team

MA, Anttila, Knudstorp, Degano, **Klochowicz**, Ramotowska, **Sbardolini**

Non-classical inferences

Free choice (FC)

(1) $\Diamond(\alpha \vee \beta) \rightsquigarrow \Diamond\alpha \wedge \Diamond\beta$

(2) Deontic FC inference [Kamp 1973]

- You may go to the beach *or* to the cinema.
- \rightsquigarrow You may go to the beach *and* you may go to the cinema.

(3) Epistemic FC inference [Zimmermann 2000]

- Mr. X might be in Victoria *or* in Brixton.
- \rightsquigarrow Mr. X might be in Victoria *and* he might be in Brixton.

Ignorance

(4) The prize is in the attic *or* in the garden \rightsquigarrow speaker doesn't know where

(5) ? I have two *or* three children. [Grice 1989]

- ▶ In the standard approach, **ignorance** inferences are conversational implicatures
- ▶ Less consensus on **FC** inferences analysed as conversational implicatures; grammatical implicatures; semantic entailments; ...

Novel hypothesis: neglect-zero

- ▶ FC and ignorance inferences are [≠ semantic entailments]
- ▶ Not the result of Gricean reasoning [≠ conversational implicatures]
- ▶ Not the effect of applications of covert grammatical operators [≠ scalar implicatures]
- ▶ But rather a consequence of something else speakers do in conversation, namely,

NEGLECT-ZERO

when interpreting a sentence speakers create mental structures representing reality¹ and in doing so they systematically neglect structures which verify the sentence by virtue of an empty configuration (*zero-models*)

- ▶ Tendency to neglect zero-models follows from the difficulty of the cognitive operation of evaluating truths with respect to empty witness sets [Nieder 2016, Bott et al, 2019]

¹ Johnson-Laird (1983) *Mental Models*. Cambridge University Press.

Novel hypothesis: neglect-zero

Illustrations

- (6) Every square is black.
- Verifier: [■, ■, ■]
 - Falsifier: [■, □, ■]
 - Zero-models: []; [△, △, △]; [◊, ▲, ◊]; [▲, ▲, ▲]
- (7) Less than three squares are black.
- Verifier: [■, □, ■]
 - Falsifier: [■, ■, ■]
 - Zero-models: []; [△, △, △]; [◊, ▲, ◊]; [▲, ▲, ▲]; [□, □, □]
- Cognitive difficulty of zero-models confirmed by experimental findings from number cognition and has been argued to explain
- the special status of 0 among the natural numbers [Nieder, 2016]
 - why downward-monotonic quantifiers are more costly to process than upward-monotonic ones (*less vs more*) [Bott et al., 2019]
 - existential import & connexive principles operative in Aristotelian logic (*every A is B ⇒ some A is B; not (if not A then A)*) [MA, 2024]
- Core idea: tendency to neglect zero-models, assumed to be operative in ordinary conversation, explains FC and related inferences

Novel hypothesis: neglect-zero

Illustrations

(8) It is raining.

- a. Verifier: [|||||]
- b. Falsifier: [○○○]
- c. Zero-models: none

(9) It is snowing.

- a. Verifier: [* * *]
- b. Falsifier: [○○○]; [|||||]; ...
- c. Zero-models: none

(10) It is raining or snowing.

- a. Verifier: [||||| | * * *]
- b. Falsifier: [○○○]
- c. **Zero-models:** [|||||]; [* * *]

- ▶ Two models in (10-c) are **zero-models** because they verify the sentence by virtue of an empty witness for one of the disjuncts
- ▶ Ignorance effects arise because such zero-models are cognitively taxing and therefore disregarded

Novel hypothesis: no-split

A closer look at the disjunctive case

(11) It is raining or snowing.

- a. Verifier: [/ / / / | * * *] [\Leftarrow “split” state]
- b. Falsifier: [. . . .]
- c. Zero-models: [/ / / /]; [* * *]

- ▶ The “split” verifier in (11-a) involves the entertainment of two alternatives, also arguably a cognitively difficult operation
- ▶ We **conjecture** that the ability to split states is acquired late
 \mapsto NO-SPLIT HYPOTHESIS
- ▶ The combination of neglect-zero and no-split can explain non-classical inferences observed in pre-school children

No-split and the acquisition of 'or'

- Basic data: some pre-school children interpret *or* as *and* [e.g., Singh *et al* 2016, Cochard 2023, Bleotu *et al* 2024]:

- (12) The boy is holding an apple or a banana = The boy is holding an apple and a banana $(\alpha \vee \beta) = (\alpha \wedge \beta)$
- (13) Every boy is holding an apple or a banana = Every boy is holding an apple and a banana $\forall x(\alpha \vee \beta) = \forall x(\alpha \wedge \beta)$
- (14) Liz can buy a croissant or a donut = Liz can buy a croissant and a donut $\Diamond(\alpha \vee \beta) = \Diamond(\alpha \wedge \beta)$

- Two different explanations:

- Singh *et al*: derive $\alpha \wedge \beta$ from $\alpha \vee \beta$ as a scalar implicature using
 $\text{exh-ALT} = \{\alpha \wedge \neg\beta, \beta \wedge \neg\alpha\}$ [or, alternatively, by innocent inclusion]
↳ children can compute scalar implicatures and can exhaustify alternatives, but don't have access to lexical alternatives
- Nihil: beside neglecting zero-models, children further lack the ability to split states, i.e. have difficulties in engaging with alternative epistemic possibilities, in picturing different ways the world might be.

BSML: teams and bilateralism

- ▶ Team semantics: formulas interpreted wrt a set of points of evaluation (a team) rather than single ones [Hodges 1997; Väänänen 2007]

Classical vs team-based modal logic

$[M = \langle W, R, V \rangle]$

- ▶ Classical modal logic: (truth in worlds)

$$M, w \models \phi, \text{ where } w \in W$$

- ▶ Team-based modal logic:

$$M, t \models \phi, \text{ where } t \subseteq W$$

Bilateral state-based modal logic (BSML)

- ▶ Teams \mapsto information states [Dekker93; Groenendijk⁺96; Ciardelli⁺19]
- ▶ Assertion & rejection conditions modelled rather than truth

$$M, s \models \phi, \text{ "}\phi\text{ is assertable in } s\text{"}, \text{ with } s \subseteq W$$

$$M, s \models \phi, \text{ "}\phi\text{ is rejectable in } s\text{"}, \text{ with } s \subseteq W$$

- ▶ Neglect-zero tendency modelled by NE [Yang & Väänänen 2017]
- ▶ BSML^F: No-split modelled via a flattening operator F [Punčochář 2024]

BSML^F: Classical Modal Logic + NE + F

Language

$$\phi := p \mid \neg\phi \mid \phi \vee \phi \mid \phi \wedge \phi \mid \Diamond\phi \mid \text{NE} \mid \text{F}$$

Bilateral team semantics

$$[M = \langle W, R, V \rangle \ \& \ s, t, t' \subseteq W]$$

$$M, s \models p \quad \text{iff} \quad \text{for all } w \in s : V(w, p) = 1$$

$$M, s \not\models p \quad \text{iff} \quad \text{for all } w \in s : V(w, p) = 0$$

$$M, s \models \neg\phi \quad \text{iff} \quad M, s \not\models \phi$$

$$M, s \not\models \neg\phi \quad \text{iff} \quad M, s \models \phi$$

$$M, s \models \phi \vee \psi \quad \text{iff} \quad \text{there are } t, t' : t \cup t' = s \ \& \ M, t \models \phi \ \& \ M, t' \models \psi$$

$$M, s \not\models \phi \vee \psi \quad \text{iff} \quad M, s \not\models \phi \ \& \ M, s \not\models \psi$$

$$M, s \models \phi \wedge \psi \quad \text{iff} \quad M, s \models \phi \ \& \ M, s \models \psi$$

$$M, s \not\models \phi \wedge \psi \quad \text{iff} \quad \text{there are } t, t' : t \cup t' = s \ \& \ M, t \not\models \phi \ \& \ M, t' \not\models \psi$$

$$M, s \models \Diamond\phi \quad \text{iff} \quad \text{for all } w \in s : \exists t \subseteq R[w] : t \neq \emptyset \ \& \ M, t \models \phi$$

$$M, s \not\models \Diamond\phi \quad \text{iff} \quad \text{for all } w \in s : M, R[w] \not\models \phi$$

$$M, s \models \text{NE} \quad \text{iff} \quad s \neq \emptyset \quad [\text{where } R[w] = \{v \in W \mid wRv\}]$$

$$M, s \not\models \text{NE} \quad \text{iff} \quad s = \emptyset$$

$$M, s \models \text{F}\phi \quad \text{iff} \quad \text{for all } w \in s : M, \{w\} \models \phi$$

$$M, s \not\models \text{F}\phi \quad \text{iff} \quad \text{for all } w \in s : M, \{w\} \not\models \phi$$

Neglect-zero effects in BSML: split disjunction

- ▶ A state s supports a **disjunction** $\phi \vee \psi$ iff s is the union of two substates, each supporting one of the disjuncts

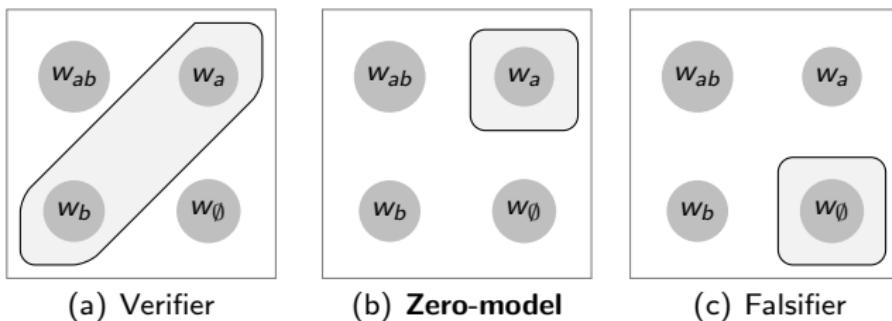
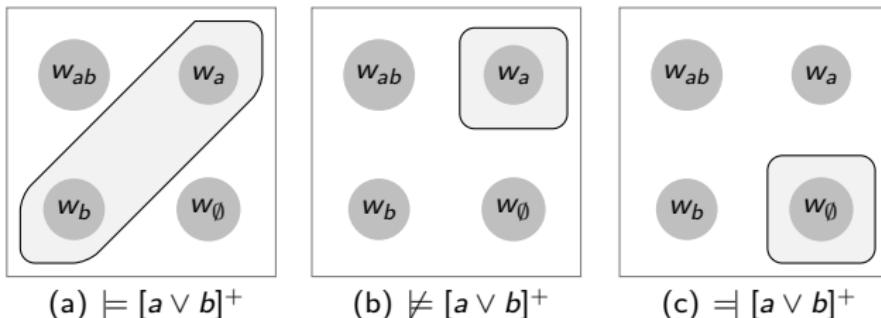


Figure: Models for $(a \vee b)$.

- ▶ $\{w_a\}$ verifies $(a \vee b)$ by virtue of an empty witness for the second disjunct, $\{w_a\} = \{w_a\} \cup \emptyset \& M, \emptyset \models b$ [→ **zero-model**]
- ▶ **Main idea:** define neglect-zero enrichments, $[]^+$, whose core effect is to rule out such zero-models
- ▶ **Implementation:** $[]^+$ defined using NE ($s \models \text{NE}$ iff $s \neq \emptyset$), which models neglect-zero in the logic

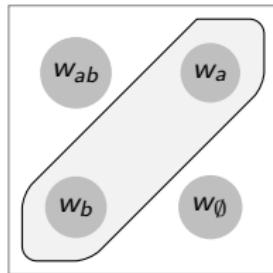
Neglect-zero effects in BSML: enriched disjunction

- s supports an **enriched disjunction** $[\phi \vee \psi]^+$ iff s is the union of two **non-empty** substates, each supporting one of the disjuncts

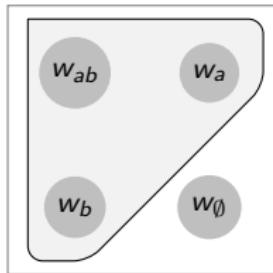


- An enriched disjunction requires both disjuncts to be live possibilities
 - (15) It is raining or snowing \rightsquigarrow It might be raining and it might be snowing
- **Main result:** in BSML $[\cdot]^+$ -enrichment has non-trivial effect only when applied to *positive* disjunctions [MA 2022]
 - ↳ we derive FC and related effects (for $[\cdot]^+$ -enriched formulas);
 - ↳ $[\cdot]^+$ -enrichment vacuous under single negation.

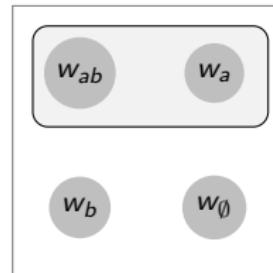
More no-zero verifiers for enriched disjunction



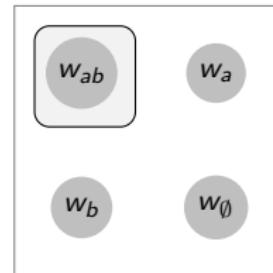
(d) no-zero & scalar
 $\models \neg(a \wedge b)$



(e) no-z & non-scalar
 $\not\models \neg(a \wedge b)$



(f) no-z, non-scalar &
no-uncertain $\not\models \neg \Box a$

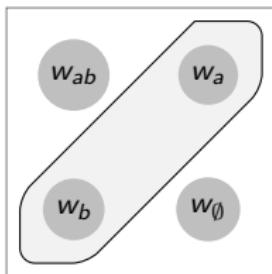


(g) no-z, non-scalar,
no-uncert. & no-split

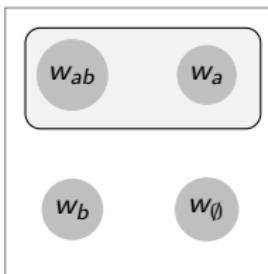
Figure: Models for enriched $[a \vee b]^+$.

Neglect-zero effects in BSML: possibility vs uncertainty

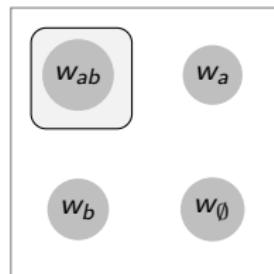
- More no-zero verifiers for $a \vee b$:



(a) scalar



(b) no-uncertain



(c) no-split

- Two components of full ignorance ('speaker doesn't know which'): ²
- (16) It is raining or it is snowing ($\alpha \vee \beta$) \sim
 - a. Uncertainty: $\neg \Box_e \alpha \wedge \neg \Box_e \beta$
 - b. Possibility: $\Diamond_e \alpha \wedge \Diamond_e \beta$ (equiv $\neg \Box_e \neg \alpha \wedge \neg \Box_e \neg \beta$)
- **Fact:** Only possibility derived as neglect-zero effect:
 - $\{w_{ab}, w_a\} \models \Diamond_e a \wedge \Diamond_e b$, but $\not\models \neg \Box_e a$
 - $\{w_{ab}, w_a\}$: a no-zero model supporting possibility but neither uncertainty nor scalar implicature ($\not\models \neg(a \wedge b)$)

²Degano, Marty, Ramotowska, MA, Breheny, Romoli, Sudo. SuB & XPRAG, 2023.

Two derivations of full ignorance

1. Neo-Gricean derivation [Sauerland 2004]

(i) Uncertainty derived through **quantity** reasoning

$$(17) \quad \alpha \vee \beta \qquad \text{ASSERTION}$$

$$(18) \quad \neg \Box_e \alpha \wedge \neg \Box_e \beta \qquad \text{UNCERTAINTY (from QUANTITY)}$$

(ii) Possibility derived from uncertainty and **quality** about assertion

$$(19) \quad \Box_e (\alpha \vee \beta) \qquad \text{QUALITY ABOUT ASSERTION}$$

$$(20) \quad \Rightarrow \Diamond_e \alpha \wedge \Diamond_e \beta \qquad \text{POSSIBILITY}$$

2. Nihil derivation

(i) Possibility derived as **neglect-zero** effect

$$(21) \quad \alpha \vee \beta \qquad \text{ASSERTION}$$

$$(22) \quad \Diamond_e \alpha \wedge \Diamond_e \beta \qquad \text{POSSIBILITY (from NEGLECT-ZERO)}$$

(ii) Uncertainty derived from possibility and **scalar reasoning**

$$(23) \quad \neg (\alpha \wedge \beta) \qquad \text{SCALAR IMPLICATURE}$$

$$(24) \quad \Rightarrow \neg \Box_e \alpha \wedge \neg \Box_e \beta \qquad \text{UNCERTAINTY}$$

Neglect-zero effects in BSML: possibility vs uncertainty

Comparison with competing accounts

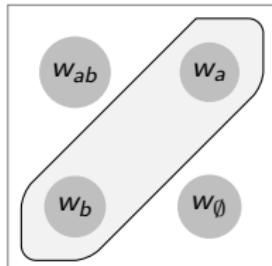
- ▶ Neo-Gricean vs Nihil predictions
 - ▶ Neo-Gricean: No possibility without uncertainty
 - ▶ Nihil: Possibility derived independently from uncertainty

Experimental study

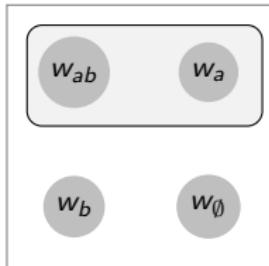
- ▶ Experimental findings in agreement with Nihil predictions [Degano et al 2023]
 - ▶ Using adapted mystery box paradigm, compared conditions in which
 - ▶ both uncertainty and possibility are false [zero-model]
 - ▶ uncertainty false but possibility true [no-zero, no-uncertain model]
 - ▶ Less acceptance when possibility is false (95% vs 44%)
- ▶ Evidence that possibility can arise without uncertainty

Neglect-zero and no-split

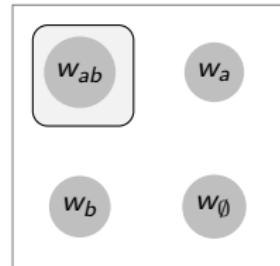
- More no-zero verifiers for $a \vee b$:



(d) scalar



(e) no-uncertain



(f) no-split

- $\{w_{ab}\}$ is a no-split verifier for the disjunction: no alternatives entertained;
- **Conjecture:** only no-split verifiers accessible to ‘conjunctive’ pre-school children [Klochowicz, Sbardolini, MA, 2024]
- Combination of no-split and no-zero gives us conjunctive *or*
- **Implementation:** uses flattening operator F

$$M, s \models F\phi \text{ iff for all } w \in s : M, \{w\} \models \phi$$

Flattening \mapsto formulas always interpreted wrt to singleton states

Illustration

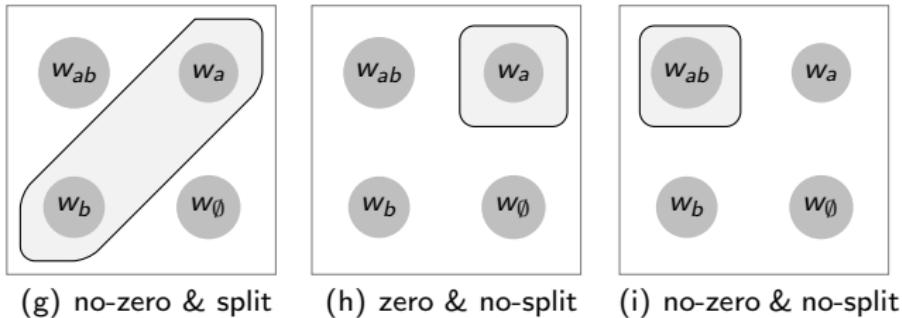


Figure: Combination of no-split and no-zero gives us conjunctive or

(25) It is raining or snowing.

- a. No-zero & split: [||||| | ***] [adult-like]
- b. Zero and no-split: [|||||] [logician]
- c. No-zero & no-split: [||||| + ***] ['conjunctive' children]

No-split: some predictions

- (26) a. $[F(\alpha \vee \beta)]^{+/*} \equiv \alpha \wedge \beta$
b. $[\forall x F(\alpha \vee \beta)]^{+/*} \equiv \forall x (\alpha \wedge \beta)$
c. $[\Diamond F(\alpha \vee \beta)]^{+/*} \equiv \Diamond(\alpha \wedge \beta)$ [≠ $\Box(\alpha \wedge \beta)$]
d. $[\neg F(\alpha \vee \beta)]^{+/*} \equiv \neg\alpha \wedge \neg\beta$
e. $[\neg F(\alpha \wedge \beta)]^* \equiv \neg\alpha \wedge \neg\beta$, but $[\neg F(\alpha \wedge \beta)]^+ \neq \neg\alpha \wedge \neg\beta$

- ▶ Two ways to model neglect-zero effects:
 - ▶ Syntactically, via pragmatic enrichment function $[]^+$ defined in terms of $NE \mapsto BSML^+$
 - ▶ Model-theoretically, by ruling out \emptyset from the set of possible states $\mapsto BSML^*$
- ▶ Both implementations derive:
 - ↳ FC effects (narrow and wide scope FC, dual prohibition, etc);
 - ↳ conjunctive or in combination with flattening (26-a-d).
- ▶ But only $BSML^*$ predicts
 - ▶ Negative FC: $\neg\Box(\alpha \wedge \beta) \leadsto \neg\Box\alpha \wedge \neg\Box\beta$ [Marty et al]
 - ▶ Homogeneity effects in combination with F (26-e) [Sbardolini23]
- ▶ Only in $BSML^+$, \emptyset is part of the building blocks (natural to assume $BSML^*$ for “conjunctive” children who plausibly do not access \emptyset)

Two views

- ▶ Two explanations of conjunctive ‘or’ in pre-school children:
 - ▶ **Grammatical view:** conjunctive children can compute implicatures but do not have access to scalar alternatives (or < and);
 - ▶ **Nihil:** conjunctive behaviour derives from the combination of two cognitive bias: no-zero and no-split.

	conjunctive or	inclusive or	exclusive or
Grammatical	exh-alt [✓]	exh-alt [no]	scalar-alt [✓]
Nihil	zero [no] & split [no]	split [✓] (or zero [✓])	split [✓] & scalar reasoning [✓]

- ▶ Two different acquisition patterns:
 - ▶ **Grammatical view:**
inclusive or < conjunctive or < exclusive or
 - ▶ **Nihil:**
conjunctive or < inclusive or < exclusive or

Conclusions

- ▶ FC and related inferences: a mismatch between logic and language
- ▶ Grice's insight:
 - ▶ stronger meanings can be derived paying more “attention to the nature and importance to the conditions governing conversation”
- ▶ Nihil proposal: stronger meanings consequences of cognitive biases
 - ▶ FC and ignorance as neglect-zero effects
 - Literal meanings (NE-free fragment) + cognitive factors (NE)
⇒ FC & possibility inferences
 - ▶ Conjunctive *or* as no-zero + no-split effect
 - Literal meanings (NE-free fragment) + cognitive factors (NE, F) ⇒ conjunctive *or*
 - ▶ Implementation in BSML^F (a team-based modal logic)

Collaborators & related (future) research

Logic

Proof theory ([Anttila, Yang](#)); expressive completeness ([Anttila, Yang](#), [Knudstorp](#)); bimodal perspective ([Knudstorp, Baltag, van Benthem, Bezhaniashvili](#)); qBSML ([van Ormondt](#)); BiUS & qBiUS ([MA](#)); typed BSML ([Muskens](#)); Aristotelian logic in qBSML \rightarrow ([MA](#)); ...

Language

FC cancellations ([Pinton, Hui](#)); modified numerals ([vOrmondt](#)); attitude verbs ([Yan](#)); conditionals ([Flachs](#)); questions ([Klochowicz](#)); quantifiers ([Ramotowska, Klochowicz, Bott, Schlotterbeck](#)); indefinites ([Degano](#)); homogeneity ([Sbardolini](#)); experiments ([Degano, Klochowicz, Ramotowska, Bott, Schlotterbeck, Marty, Breheny, Romoli, Sudo](#)); acquisition ([Sbardolini, Klochowicz](#)); ...

THANK YOU!³

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