Towards a principled logic of anaphora*

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In the absence of alternatives with comparable empirical coverage, the *dynamic* approach to anaphora has shown an impressive longevity, having been refined and extended in the decades since Heim (1982) and Kamp's (1981) foundational work. Like the dynamic approach to presupposition projection, it has however been criticized on the grounds of explanatory adequacy — dynamic semantics tailors the entry of each of the logical operators in order to derive the desired accessibility generalizations. Furthermore, there are empirical wrinkles — it fails to account for, e.g., double negation and bathroom sentences. There has long been an intuition that a more explanatory account of anaphora is possible, using the same tools that have been developed for presupposition projection (George 2007, 2008, Schlenker 2008, 2009, a.o.). In this paper, I develop a simple, predictive logic of anaphora — *Dynamic Alternative Semantics* — framed as an extension of Groenendijk & Stokhof's (1991) *Dynamic Predicate Logic*, using a strong Kleene trivalent semantics as a logical substrate. I argue that the resulting theory provides a much more principled treatment of the dynamics of the logical connectives, and furthermore captures data that is problematic for previous theories. The theory will appear to over-generate, but in the latter half of the paper, I'll demonstrate that many of the accessibility generalizations in Groenendijk & Stokhof 1991, assumed in much subsequent work, are confounded by pragmatic factors. Once supplemented with an independently motivated pragmatic component, Dynamic Alternative Semantics is sufficiently constrained.

1. Introduction

Since its inception in the 1980s (Heim 1982, Kamp 1981), Dynamic Semantics (ds) has been an extremely rich research enterprise, with important results in the domains of, e.g., anaphora, presupposition projection, and epistemic modality. Initially, ds was motivated by the observation that singular pronouns can co-vary with singular indefinites in a broader range of environments

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than a classical semantics would lead us to expect. Concretely, the two phenomena motivating DS are *discourse anaphora* and *donkey anaphora*, as illustrated in (1) and (2) respectively:[1]

(1) I invited a^1 philosopher; I'm relieved that she_1 came.

(2) Everyone who invited a^1 philosopher was relieved that she_1 came.

The phenomena in (1) and (2) have been taken to motivate a logical system in which *Egli's theorem* and its corrolary hold:

Observation 1.1 (Egli's theorem). $\exists^n\, \phi \wedge \psi \Leftrightarrow \exists^n\, (\phi \wedge \psi)$

Observation 1.2 (Egli's corrolary). $\exists^n\, \phi \rightarrow \psi \Leftrightarrow \forall^n\, (\phi \rightarrow \psi)$

There are many varieties of DS that fulfill this desideratum, and two separate traditions: *dynamic interpretation* (initiated by Heim's *File Change Semantics*) and *dynamic representation* (initiated by Kamp's *Discourse Representation Theory*).[2] I believe that many of the points raised in this paper apply equally to dynamic representation theories, but for concreteness, I'll be focusing on dynamic interpretation theories, and specifically Groenendijk & Stokhof's (1991) Dynamic Predicate Logic (DPL). DPL has been extremely influential in the dynamic literature, and many theories which extend DS to a broader range of empirical phenomena extend DPL (see, e.g., Groenendijk, Stokhof & Veltman 1996 on epistemic modality, and van den Berg 1996 on generalized quantifiers and discourse plurals, etc.). In the next section, we'll consider some of the more prominent issues for DS as a theory of anaphora to singular indefinites.

1.1. Double negation and bathrooms

It can be observed that negation renders singular indefinites *inaccessible* as antecedents for subsequent pronouns. We can show this most easily by using an Negative Polarity Item (NPI) to disambiguate scope:[3]

(4) # It's not true that any^1 philosopher attended this talk. She_1 was unwell.

We can use negative indefinites to make the same point, on the assumption that negative indefinites can be decomposed into sentential negation and existential quantification.

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[1]By convention, I'll decorate sentences of English with superscript and subscript indices to indicate the logical binder and bound expression(s) respectively.

[2]The terminology here is borrowed from Yalcin 2013.

[3]NPIs nevertheless license discourse and donkey anaphora, as illustrated by the examples in (3a) and (3b) respectively:

(3) a. Everyone [who read any^1 of these books and subsequently criticized it_1] is a charlatan.

b. Everyone [who read any^1 of these books] recommended it_1 to their friends.

(5) #No[1] philosopher attended this talk. She$_1$ was unwell.

In DS, the semantics of negation in tailored to derive this. Without going into the details of, e.g., the DPL interpretation schema, the intuitive idea is that indefinites introduce Discourse Referents (DRS), but negation eliminates any DRS in its scope; in the parlance of DS, we say that negation is *externally static*. We'll refer to this as a "destructive" semantics for negation. An immediate consequence of destructive negation is that, once dead, a DR cannot be resurrected. This means that, in DS, doubly-negated sentences can't introduce DRS.

As has long been recognized (Groenendijk & Stokhof 1991, Krahmer & Muskens 1995), this doesn't seem to be a good prediction — an indefinite in the scope of two negative operators can antecede a subsequent pronoun. This is illustrated by example (6).[4]

(6) It's not true that NO[1] philosopher is attending this talk;
She$_1$'s sitting in the back!

This suggests that, perhaps we want an underlying logical system in which Double Negation Elimination (DNE) is valid — we can frame the issue for DS in the following way: it strays too far from the classical, thereby rendering certain desirable logical principles no longer valid.[5]

The problem of double negation affects the account of other data too. For example, consider Partee's famous *bathroom sentences*. Bathroom sentences demonstrate a parallel between presupposition projection and anaphora in disjunctive sentences; in DS, the fact that the presupposition introduced by *the bathroom* fails to project is taken to indicate that the second disjunct is interpreted in the context of the negation of the first, and the presupposition of the second disjunct is thereby locally satisfied (Beaver 2001). Although less often discussed, the licensing of anaphoric pronouns completely parallels presupposition projection in this respect, as illustrated by the acceptability of (8b).

(8) a. Either there is no bathroom, or the bathroom is upstairs.
b. Either there is no[1] bathroom, or it$_1$'s upstairs.

Naturally, we'd like to extend the intuitive explanation for the presuppositional case to the anaphoric case, but due to destructive negation, interpreting the second disjunct in the context

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[4] Emphasis is indicated by small caps — although I don't think that this is *essential* for (6) to be a felicitous utterance, my judgement is that this results in a more natural-sounding sentence. Double-negation is clearly a marked option, and seems to be subject to additional, poorly-understood discourse requirements. This is unsurprising, given the availability of the positive counterpart as a competitor. The discourse conditions allowing for doubly negated sentences, and how this affects their prosody, is something that requires further investigation; I will abstract away from these questions in this paper.

[5] It is however worth mentioning the claim (Gotham 2019) that (6) comes with an additional inference that its positive counterpart (7) lacks — namely, that *exactly one* philosopher attended the talk. This suggests that perhaps we want our logic to only validate a limited form of DNE — we'll touch upon this point briefly in §4.1.

(7) A[1] philosopher is attending this talk; She$_1$'s sitting in the back.

of the negation of the first doesn't help explain the availability of anaphora. In other words, we'd like to explain the possibility of anaphora in (8b) in terms of anaphora in (9), but due to the design features of DS, this move is blocked.

(9) Either there is no bathroom, or there isn't no^1 bathroom and it$_1$'s upstairs.

1.2. Explanatory adequacy

DS more broadly has often been criticized on the grounds of explanatory adequacy, although the discussion tends to revolve more around presupposition projection than anaphora (Soames 1989). This is an especially forceful objection in the domain of presupposition projection, since there are competing, less stipulative theories which make equivalent, if not superior, empirical predictions to a dynamic approach (see, e.g., Schlenker 2008, 2009, George 2008, 2007). The point, however, can be made for the dynamic approach to anaphora too, which, arguably has no competitors which cover all the same data.[6]

In DS, the directionality of the flow of referential information is regulated by the semantics of the logical connectives. For example, the semantics of conjunctive sentences in DS in essence stipulates that the second conjunct is interpreted in the context of the first, thus predicting a linear asymmetry in anaphoric licensing. The problem, in a nutshell, is that it's easy to give an alternative semantics for conjunction which interprets the first conjunct in the context of the second, while still maintaining the truth-conditional contribution of conjunction. Therefore, despite purporting to account for the contrast in (10), DS operates at a highly descriptive level.

(10) a. A philosopher^1 is attending this talk and she$_1$'s sitting in the back.

b. #She$_1$'s sitting in the back and a^1 philosopher is attending this talk.

What would count as a more explanatory DS? Arguably one on which the dynamic entries for the logical connectives can be derived in a systematic way from their static counterparts — see, e.g., George 2008 for a simple trivalent theory of presupposition projection which has this character. As of yet, there is no especially prominent approach to anaphora which has the same empirical coverage as DS, while being less stipulative in just the way suggested here.[7]

The largely conceptual issue of explanatory adequacy may seem at first blush to be completely independent of the empirical issues with negation and disjunction in DS. As we'll see however,

[6] A prominent alternative approach to anaphora is the so-called *e-type* theory, according to which pronouns behave semantically like definite descriptions, and which typically invokes quantification over situations (Heim 1990, Elbourne 2005, 2013). The e-type approach was formulated as an alternative account of donkey anaphora, and, to my knowledge, there is no "official" e-type account of discourse anaphora. The extent to which this is a viable competitor for donkey anaphora is somewhat besides the point, since the empirical remit of DS extends far beyond that of the e-type approach. Furthermore, the e-type approach is no less stipulative than DS — a glance at Elbourne (2013: ch. 2) is enough to indicate that, using situation semantics, one must assume a rather baroque semantics for the logical operators. See Rothschild & Mandelkern 2017 for a useful comparison between the two approaches.

[7] See Rothschild 2017 and Mandelkern 2020 for two notable exceptions, within a static framework. I discuss these works briefly in §4.2.

developing a dynamic logic on a firmer footing will, as a consequence, at least partially address these issues.

The paper will proceed as follows: in the next section, I'll develop a new dynamic logic, which I'll call Dynamic Alternative Semantics (DAS), starting out with the basic building blocks of DPL. As we'll see, DAS is somewhat more expressive than DPL, allowing us to distinguish between the positive vs. negative information conveyed by a given sentence. This will make it well-suited to tackling the problem of negation in DS. I'll argue that it's possible to capture almost all of the most important data motivating standard DS, by simply lifting the strong Kleene connectives into a dynamic setting in a systematic way. Furthermore, DAS goes beyond the empirical coverage of standard dynamic theories, and accounts for double negation and bathroom sentences. In the remainder of the paper, I'll demonstrate that some of the apparently problematic predictions of DAS are less problematic than they may at first appear — concretely, I'll show that the accessibility generalizations assumed by, e.g., Groenendijk & Stokhof are confounded by pragmatic factors. In order to demonstrate this, I'll intensionalize DAS, and ground it in a Stalnakerian pragmatics. Finally, I'll conclude by comparing DAS to some recently proposed explanatory alternatives to DS.

2. Dynamic alternative semantics

2.1. Background: Dynamic Predicate Logic

Groenendijk & Stokhof (1991) give a dynamic interpretation for a simple first-order predicate calculus. The syntax, which we'll maintain in DAS, is that of standard predicate logic.[8] The interpretation of a sentence is given relative to a first-order model $M \coloneqq \langle D, I\rangle$, where the *domain* ($D$) is a non-empty set of individuals, and I assigns interpretations to predicate symbols as sets of tuples of individuals in a standard way. In definition 2.1, we give a somewhat non-standard summary of the DPL interpretation schema — the interpretation of a sentence relative to an input assignment g, and a model M, is a *set* of output assignments.

Definition 2.1 (Semantics of DPL).

$$\begin{aligned}
[\![P\ t_1 \dots t_n]\!]^g_{DPL} &= \{\, g \mid \langle [\![t_1]\!]^g, \dots, [\![t_n]\!]^g \rangle \in I(P) \,\}\\
[\![\neg\, \phi]\!]^g_{DPL} &= \{\, g \mid \neg\, \exists h \in [\![\phi]\!]^g_{DPL} \,\}\\
[\![\phi \wedge \psi]\!]^g_{DPL} &= \{\, i \mid \exists h[h \in [\![\phi]\!]^g_{DPL} \wedge i \in [\![\psi]\!]^h_{DPL}] \,\}\\
[\![\phi \vee \psi]\!]^g_{DPL} &= \{\, g \mid ([\![\phi]\!]^g_{DPL} \cup [\![\psi]\!]^g_{DPL}) \neq \varnothing \,\}\\
[\![\phi \rightarrow \psi]\!]^g_{DPL} &= \{\, g \mid ([\![\phi]\!]^g_{DPL} \subseteq \{\, h \mid [\![\psi]\!]^h_{DPL} \neq \varnothing \,\}) \,\}\\
[\![\exists^n\, \phi]\!]^g_{DPL} &= \{\, h \mid \exists x[h \in [\![\phi]\!]^{g^{[1 \mapsto x]}}_{DPL}] \,\}
\end{aligned}$$

By inspecting the above clauses, one can see how the flow of referential information is militated by the interpretation schema. For example, negative, disjunctive, and implicational sentences all close off the output of the contained sentence(s). This predicts that negation, disjunction, and

[8] We'll use natural numbers $n \in \mathbb{N}$ as variable symbols, $a, b, c, \dots$ as individual constants, and $A, B, C, \dots$ as predicate symbols.

implication are all *externally static* operators. Furthermore, in a disjunctive sentence, the second disjunct is not sensitive to the referential information introduced by the first. This predicts that disjunction is *internally static*. The main thing to note is that the semantics is tailored to derive generalizations concerning possible anaphoric dependencies, in a way that doesn't obviously follow from the truth-conditional contribution of the logical connectives. After introducing DAS, in the next sections, we'll furthermore argue in §3 that the generalizations assumed by G&S are at least partially analyzable in the pragmatic component.

2.2. Basic building blocks

Much like Groenendijk & Stokhof (1991) we'll proceed by giving a dynamic interpretation for a simple first-order predicate calculus. Interpretation will be given relative to a first-order model $M := \langle D, I, T\rangle$, where D is a non-empty set of individuals, T is the set of truth-values, and I assigns interpretations to predicates as sets of tuples of individuals in a standard way. Since we'll be developing a *trivalent* semantics, T consists of *true,false* ($\top, \bot$) and third truth-value #, which we'll call *maybe*, to reflect it's role in the trivalent substrate. The main difference from DPL is that the interpretation of a sentence relative to an assignment g, and a model M is a *set of truth-value/assignment pairs* (we'll omit the model parameter wherever possible). This will afford the system more expressive power DPL.[9]

2.3. Atomic sentences

We'll assume that assignments may be partial; this means that atomic sentences may return a #-tagged output. We'll formalize this idea using Beaver's (2001) ∂-operator, which converts *false* to *maybe*.[10]

∂	
1	1
0	#
#	#

Table (1): Beaver's (2001) ∂-operator

Definition 2.2 (Atomic sentences)**.** We provide provisions here for dealing with a monadic predicate and a single term, with separate clauses for variables and individual constants. These are generalized to sequences of terms in the obvious way.

$$[\![P\ n]\!]^g := \{\, (\partial\ (n \in \mathsf{dom}\ g) \wedge g_n \in I(P), g)\,\}$$

$$[\![P\ c]\!]^g := \{\, (I(c) \in I(P), g)\,\}$$

[9]This presentation is inspired by Charlow's (2014, 2019b) monadic dynamic semantics.

[10]Note for concreteness that we assume a weak Kleene semantics for meta-language conjunction ($\wedge$), i.e., if any conjuncts in the meta-language are *maybe*, then the entire conjunctive statement is *maybe*.

It will frequently be illustrative to consider the interpretation of a sentence relative to a privileged assignment: the *initial assignment* $g_\top$, which is the unique assignment whose domain is the empty set. An atomic sentence with free variables interpreted relative to the initial assignment will always return the maybe-tagged input assignment, as illustrated in (11a). As long as every variable is in the domain of the input assignment, the sentence will return the true- or false-tagged input assignment depending on the model; this is illustrated in (11b).

(11) a. $[\![P\ 1]\!]^{g_\top} = \{ (\#, g_\top) \}$

b. $[\![P\ 1]\!]^{[1\mapsto a]} = \{ (a \in I(P), [1 \mapsto a]) \}$

2.4. Existential quantification and negation

2.4.1. DPL existential quantification in DAS

Although our semantics for the other logical operators will be straightforward liftings of their strong Kleene counterparts, we'll need to say something special about existential quantification, much like every incarnation of DS. In order to spell-out how existential quantification works in DAS, it will be useful to decompose it into two components — a DPL-like existential quantifier, which we'll write as ε^n, and a closure operator which restricts the introduction of DRS, which we'll come to later on.

Definition 2.3 (DPL existential quantification in DAS)**.**

$$[\![\varepsilon^n\ \phi]\!]^g = \{ (t,h) \mid \exists x \in D[(t,h) \in [\![\phi]\!]^{g^{[1\mapsto x]}}] \}$$

DPL existential quantification, in DAS, introduces an indeterminate DR n with respect to both the positive and negative information associated with a sentence.[11]

(12) $$\begin{aligned}[\![\varepsilon^1\ P\ 1]\!]^g &= \{ (t,h) \mid \exists x \in D[(t,h) \in [\![P\ 1]\!]^{g^{[1\mapsto x]}}] \} \\ &= \{ (x \in I(P), g^{[1\mapsto x]}) \mid x \in D \}\end{aligned}$$

Equivalently:

(13) $$[\![\varepsilon^1\ P\ 1]\!]^g = \{ (\top, g^{[1\mapsto x]}) \mid x \in D \wedge x \in I(P) \} \cup \{ (\bot, g^{[1\mapsto x]}) \mid x \in D \wedge x \notin I(P) \}$$

Assume a simple domain $D \coloneqq \{ a,b,c \}$, and $I(P) = \{ a,b \}$, the result of computing (13) is given in (14). Note that, in the output, assignments are paired with a truth-value. We'll refer to this as the *polarity* of the output assignments — assignments are *true-tagged* if they map 1 to someone who is a P, and *false-tagged* if they map 1 to someone who isn't a P.

[11] As is standard, we write $g^{[n\mapsto x]}$ to mean: the assignment that at most differs from g in that $g_n = x$. In the absence of further restriction, this of course means that an indefinite can overwrite previously introduced DRS, just as in DPL. See §3.7 for further discussion.

(14) $[\![\varepsilon^1\ P\ 1]\!]^{g_\top} = \{(\top,[1\mapsto a]),(\top,[1\mapsto b]),(\bot,[1\mapsto c])\}$

In order to capture some of the same accessibility generalizations as DPL, we'll need to define DAS existential quantification in terms of an additional closure operator. In order to see why this is necessary, it will be useful to first give the semantics for negation in DAS, and show its interactions with DPL existential quantification.

2.4.2. Negation and positive/negative extensions

Negation in DAS is simply *strong Kleene* negation ($\neg_s$) lifted into a dynamic setting, as defined in definition 2.4; Strong Kleene is applied *pointwise* to each of the truth-values in the output of the contained sentence.[12] The truth-table for strong Kleene negation is given in fig. 1; strong Kleene negation has the same semantics as classical negation, only it projects uncertainty. We'll discuss how to derive a strong Kleene semantics for the logical operators systematically in §2.5.

Definition 2.4 (Negation)**.**

$$[\![\neg\,\phi]\!]^g = \{(\neg^s\,t,h) \mid (t,h)\in[\![\phi]\!]^g\}$$

$\neg^s$	
1	0
0	1
#	#

Figure (1): Negation in strong Kleene

DAS will swiftly become difficult to reason about, so at this stage it will be useful to define two extremely helpful auxiliary notions: the *positive* and *negative* extension of a sentence. As one might expect, the positive extension of ϕ relative to g is simply all of the assignments in the interpretation of ϕ relative to g tagged true, and likewise but tagged false for the negative extension.

Definition 2.5 (Positive and negative extension)**.**

$$[\![\phi]\!]^g_+ = \{h \mid (\top,h)\in[\![\phi]\!]^g\}$$
$$[\![\phi]\!]^g_- = \{h \mid (\bot,h)\in[\![\phi]\!]^g\}$$

For completeness, we can also define the *maybe extension*:

$$[\![\phi]\!]^g_u = \{h \mid (\#,h)\in[\![\phi]\!]^g\}$$

[12] We refer to this entry as "lifted", since it can be derived from strong Kleene negation in a principled fashion — see §2.5 for discussion.

To illustrate how this works, we give the positive/negative/maybe-extensions of an atomic sentence below:

(15) a. $[\![P\ 1]\!]^g_+ = \{g \mid 1 \in \mathsf{dom}\ g \wedge g_1 \in I(P)\}$

b. $[\![P\ 1]\!]^g_- = \{g \mid 1 \in \mathsf{dom}\ g \wedge g_1 \notin I(P)\}$

c. $[\![P\ 1]\!]^g_u = \{g \mid 1 \notin \mathsf{dom}\ g\}$

Next, we'll define the *static truth-value* of a sentence of DAS in terms of its extensions:

Definition 2.6 (Truth)**.** We'll write $|\phi|^g$ for the static truth-value of a sentence ϕ at g, defined as follows:

$$|\phi|^g = \begin{cases} 1 & [\![\phi]\!]^g_+ \neq \varnothing \\ 0 & [\![\phi]\!]^g_+ = \varnothing \wedge [\![\phi]\!]^g_- \neq \varnothing \\ \# & [\![\phi]\!]^g_+ = [\![\phi]\!]^g_- = \varnothing \wedge [\![\phi]\!]^g_u \neq \varnothing \end{cases}$$

It's helpful to think of DAS as consisting of two DPL-like logics, computing the positive and negative information conveyed by a sentence in tandem. Using the notion of positive and negative extension, we can already establish some useful equivalences involving negation. Since all that negation does is flip the classical truth values, the positive extension of a negated sentence is the negative extension of the contained sentence, and the negative extension of a negated sentence is the positive extension of the contained sentence. The maybe extension of a negated sentence is the same as that of the contained sentence, since strong Kleene negation projects uncertainty. This is shown in Observation 2.1.

Observation 2.1.

$$[\![\neg\,\phi]\!]^g_+ = [\![\phi]\!]^g_-$$
$$[\![\neg\,\phi]\!]^g_- = [\![\phi]\!]^g_+$$
$$[\![\neg\,\phi]\!]^g_u = [\![\phi]\!]^g_u$$

Due to observation 2.1, it's obvious that a double negated sentence will be equivalent to its positive counterpart.[13]

Observation 2.2 (Double negation)**.**

$$[\![\neg\,\neg\,\phi]\!]^g_+ = [\![\neg\,\phi]\!]^g_- = [\![\phi]\!]^g_+$$
$$[\![\neg\,\neg\,\phi]\!]^g_- = [\![\neg\,\phi]\!]^g_+ = [\![\phi]\!]^g_-$$

For the time being, we simply note that this is a feature of the logical system as stated. We'll refrain from demonstrating that this makes good predictions until we arrive at our final semantics for existential quantification. For the time being, we can demonstrate that our semantics for negation, in tandem with DPL existential quantification will make bad empirical predictions. In order to see this, first consider the positive and negative extensions of the existentially-quantified sentence (16), given in (17a) and (17b) respectively.

[13] We call two sentences ϕ and ψ "equivalent" in this paper iff $[\![\phi]\!]^g_+ = [\![\psi]\!]^g_+$ and $[\![\phi]\!]^g_- = [\![\psi]\!]^g_-$.

(16) Someone[1] walked in. $\varepsilon^1\ W\ 1$

(17) a. $[\![\varepsilon^1\ W\ 1]\!]^g_+ = \{\, g^{[1\mapsto x]} \mid x \in D \wedge x \in I(W)\,\}$

b. $[\![\varepsilon^1\ W\ 1]\!]^g_- = \{\, g^{[1\mapsto x]} \mid x \in D \wedge x \notin I(W)\,\}$

Based on (2.1) it's easy to see that this will erroneously predict that negation fails to roof the dynamic scope of an existential. This is because negation in DAS flips the polarities of the output assignments, so a sentence such as "it's not the ase that anyone[1] walked in" is predicted to introduce a DR, corresponding to someone who *didn't* walk in.

(18) a. $[\![\neg\,\varepsilon^1\ W\ 1]\!]^g_+ = \{\, g^{[1\mapsto x]} \mid x \in D \wedge x \notin I(W)\,\}$

b. $[\![\neg\,\varepsilon^1\ W\ 1]\!]^g_- = \{\, g^{[1\mapsto x]} \mid x \in D \wedge x \in I(W)\,\}$

Essentially, the problem with DPL existential quantification, and negation as defined, is that the operators scopally commute. In effect, this only allows one to reason about wide-scope readings of existential quantifiers.

Observation 2.3 (ε^n and $\neg$ scopally commute)**.**

$$\varepsilon^n\,\neg\,\phi \Leftrightarrow \neg\,\varepsilon^n\,\phi$$

From this, we could conclude that there is something wrong with the semantics of negation that we've adopted — this is essentially the route taken in DPL. However, there is something conceptually appealing about the semantics for negation we've given — as we'll see in §2.5 it can be derived as a straightforward lifting of strong Kleene negation. In order to maintain our semantics for negation, therefore, we'll give the semantics for existential quantification in DAS in terms of an additional operator †, which we turn to now.

2.4.3. Positive closure

The idea which we'll pursue is that existential quantification is constrained, such that it may *only* introduce a DR with respect to the positive information conveyed by a sentence.[14] In order to capture this intuition, we define a sentential closure operation *positive closure* (†), which takes a sentence ϕ and (i) just returns the true-tagged outputs of ϕ, if there are any, (ii) just returns the false-tagged input, if ϕ is *false*, and (iii) just returns the maybe-tagged input, if ϕ is *maybe* (assuming the notion of truth defined in definition 2.6).

Definition 2.7 (Positive closure)**.**

$$\begin{aligned}[\![\dagger\,\phi]\!]^g = {} & \{\,(\top,h) \mid (\top,h) \in [\![\phi]\!]^g\,\} \\ & \cup \{\,(\bot,g) \mid \neg\exists(\top,h) \in [\![\phi]\!]^g \wedge \exists(\bot,i) \in [\![\phi]\!]^g\,\} \\ & \cup \{\,(\#,g) \mid \neg\,\exists(\top,h) \in [\![\phi]\!]^g \wedge \neg\,\exists i(\bot,i) \in [\![\phi]\!]^g \wedge \exists(\#,j) \in [\![\phi]\!]^g\,\}\end{aligned}$$

[14] Mandelkern (2020) independently develops a similar idea, in a substantially different formal setting. See §4.2 for discussion.

It may be helpful to consider the semantics of positive closure in terms of positive/negative/maybe extensions.

(19) a. $[\![\dagger\ \phi]\!]^g_+ = [\![\phi]\!]^g_+$

b. $[\![\dagger\ \phi]\!]^g_- = \{\, g \mid |\phi|^g = \bot \,\}$

c. $[\![\dagger\ \phi]\!]^g_u = \{\, g \mid |\phi|^g = \#\,\}$

2.4.4. Existential quantification in DAS

We can now give our final semantics for existential quantification in terms of DPL existential quantification and positive closure:

Definition 2.8 (Existential quantification in DAS)**.**

$$\exists^n\ \phi \Leftrightarrow \dagger\ \varepsilon^n\ \phi$$

As usual, it will be useful to first consider the positive/negative/maybe-extension of an existentially quantified sentence.

(20) a. $[\![\exists^n\ \phi]\!]^g_+ = [\![\varepsilon^n\ \phi]\!]^g_+$

b. $[\![\exists^n\ \phi]\!]^g_- = \{\, g \mid [\![\varepsilon^n\ \phi]\!]^g_+ = \varnothing \wedge [\![\varepsilon^n\ \phi]\!]^g_- \neq \varnothing \,\}$

c. $[\![\exists^n\ \phi]\!]^g_u = \{\, g \mid [\![\varepsilon^n\ \phi]\!]^g_+ = [\![\varepsilon^n\ \phi]\!]^g_- = \varnothing \wedge [\![\varepsilon^n\ \phi]\!]^g_u \neq \varnothing \,\}$

Now, based on the semantics above, it should be clear that DAS existential quantification does *not* scopally commute with negation; in fact, the negation of an existential statement is guaranteed to be a *test*. We illustrate with the simple sentence in (21).

(21) It's not the case that anyone[1] walked in. $\neg\ \exists^1\ W\ 1$

(22) a. $[\![\neg\ \exists^1\ W\ 1]\!]^g_+ = \{\, g \mid I(W) = \varnothing \,\}$

b. $[\![\neg\ \exists^1\ W\ 1]\!]^g_- = \{\, g^{[1\mapsto x]} \mid x \in D \wedge x \in I(W) \,\}$

It should already be easy to see that this logic will validate DNE, predicting that doubly-negated sentences convey the same referential information as the contained (positive) sentence. This is because, if we add another negation to (21), the positive extension of the resulting sentence will just be as in (22b)

(23) a. $[\![\neg\ \neg\ \exists^1\ W\ 1]\!]^g_+ = \{\, g^{[1\mapsto x]} \mid x \in D \wedge x \in I(W) \,\}$

b. $[\![\neg\ \neg\ \exists^1\ W\ 1]\!]^g_- = \{\, g \mid I(W) = \varnothing \,\}$

2.5. Strong Kleene

As we've emphasized, in order to develop a more explanatory dynamic framework, we'd like a theory in which the dynamics of the truth-functional operators can be systematically derived, rather than stipulated. In order to do this, we'll build DAS on top of a strong Kleene trivalent substrate; a strong Kleene semantics for the truth-functional connectives arises from an interpretation of the third truth value as representing a state of *uncertainty whether true or false*. The predictiveness of DAS will be a by-product of the fact that the strong Kleene connectives can be systematically derived from their bivalent counterparts, so it will be useful to briefly outline how this is typically accomplished.

In order to simplify the presentation, it will be convenient to take the three truth-values to stand in for an isomorphic three-membered set consisting of sets of bivalent truth-values, as in (24).

(24) $\{\overbrace{\{1\}}^{\top}, \overbrace{\{0\}}^{\bot}, \overbrace{\{1,0\}}^{\#}\}$

The strong Kleene operators can be derived systematically by simply applying the bivalent operators (which we'll indicate with a subscript b) *pointwise* to the values in (24).[15] It's easy to see that negation will thereby project uncertainty, since applying negation pointwise to $\{1,0\}$ is the identity function. For the binary connectives, projection will depend on whether uncertainty regarding one of the bivalent values affects the value of the complex sentence as a whole; irrelevant uncertainty is disregarded.[16]

(25) a. $\neg_s T := \{\neg_b t \mid t \in T\}$

b. $T \wedge_s U := \{t \wedge_b u \mid t \in T, u \in U\}$

c. $T \vee_s U := \{t \vee_b u \mid t \in T, u \in U\}$

d. $T \rightarrow_s U := \{t \rightarrow_b u \mid t \in T, u \in U\}$

In order to get the truth-tables for the strong Kleene operators, we simply map the three membered set in (24) back to *true*, *false*, and *maybe*. The result is the following strong Kleene semantics for the truth-functional operators.

$\neg^s$	
1	0
0	1
#	#

$\wedge^s$	1	0	#
1	1	0	#
0	0	0	0
#	#	0	#

$\vee^s$	1	0	#
1	1	1	1
0	1	0	#
#	1	#	#

$\rightarrow^s$	1	0	#
1	1	0	#
0	1	1	1
#	1	#	#

Figure (2): The logical operators in strong Kleene

For DAS, it will be important to make reference to the truth tables in Figure 2, although the algorithm outlined here won't play a direct role in theory. It is however important to bear in

[15]This is a somewhat different presentation of the algorithm discussed in George (2008).
[16]We use T, U here as variables ranging over the values in (24)

mind that these truth tables can be derived by reasoning about uncertainty regarding bivalent truth-values, as formalized in (25) (see Krahmer 1998, George 2007, 2008, 2014 for discussion). This procedure can in principle be generalized to more complex operators, such as first-order and generalized quantifiers (see especially George 2008 and Fox 2013), but in the following we'll focus almost exclusively on the logical connectives.

We take strong Kleene to be reasonable starting point, since we agree with Rothschild 2017: p. 1 that: "[...] when the dust has settled, this remains the simplest viable treatment of presupposition projection on the market". In the literature on presupposition projection, it has been noted that a simple strong Kleene semantics predicts *symmetric* projection, which is typically taken to be incorrect (but see Schlenker 2008 for discussion). In order to derive asymmetric projection, a common strategy has been to incrementalize strong Kleene (George 2008). In DAS, it won't be necessary to alter the lean strong Kleene trivalent substrate — incrementality will emerge as a by-product of the dynamic layer.

In order to lift the truth-functional operators systematically into a dynamic setting, the basic idea will be to apply to the operators pointwise to each truth-value in the trivalent logical substrate, while passing referential information from left-to-right.

Definition 2.9 (Dynamicizing truth-functional operators)**.** Given a one-place truth-functional operator f, the interpretation of f in DAS is as follows:

$$[\![f\ \phi]\!]^g = \{\, (\mathbf{f}\ t, h) \mid (t,h) \in [\![\phi]\!]^g \,\}$$

Given a two-place truth-functional operator R, the interpretation of R in DAS is as follows:

$$[\![\phi\ R\ \psi]\!]^g = \{\, (t\ \mathbf{R}\ u, i) \mid \exists h[(t,h) \in [\![\phi]\!]^g \wedge (u,i) \in [\![\psi]\!]^h] \,\}$$

N.b., that in the meta-language $\mathbf{f}$ and $\mathbf{R}$ are the interpretations of f, R as truth-functional operators.

This informal algorithm will be sufficient for our purposes, but see section A for an explicit treatment in terms of the `State.Set` applicative functor, within the context of a compositional fragment.

2.6. Conjunction

2.6.1. Strong Kleene in a dynamic setting

In order to get the semantics for conjunction in DAS, all we need to do is lift strong Kleene conjunction into a dynamic setting. The result of applying our informal algorithm in definition 2.9 to strong Kleene conjunction is given in definition 2.10.

Definition 2.10 (Conjunction in DAS)**.**

$$[\![\phi \wedge \psi]\!]^g = \{\, (t \wedge^s\ u, i) \mid \exists h[(t,h) \in [\![\phi]\!]^g \wedge (u,i) \in [\![\psi]\!]^h] \,\}$$

Now that we have the notions of positive and negative extension, we can also reason about the positive and negative extension of complex sentences with lifted strong Kleene conjunction. In order to do this, we consider the different ways in which strong Kleene conjunction may return true, i.e., only if both conjuncts are true. We therefore compute the relational composition of the positive extensions of the conjuncts (i.e., DPL conjunction).[17]. This is indicated in (26a). In order to compute the *negative extension*, we consider the different ways in which strong Kleene conjunction may return false, i.e., if either conjunct is false. We therefore compute the relational composition of the positive/negative/maybe-extension of the first conjunct and the negative extension of the second, and the relational composition of the negative extension of the first conjunct, and the positive/negative/maybe-extension of the second, and gather up the results, as indicated in (26b).

(26) a. $[\![\phi \wedge \psi]\!]^g_+ = \{\, i \mid \exists h[h \in [\![\phi]\!]^g_+ \wedge i \in [\![\psi]\!]^h_+]\,\}$

b. $[\![\phi \wedge \psi]\!]^g_- = \{\, i \mid \exists h[h \in [\![\phi]\!]^g_- \wedge (*, i) \in [\![\psi]\!]^h]\,\}$
$\cup \{\, i \mid \exists h[(*, h) \in [\![\phi]\!]^g \wedge i \in [\![\psi]\!]^h_-]\,\}$

2.7. Discourse anaphora and Egli's theorem

It should be clear at this point that DAS will deal easily with standard cases of discourse anaphora, and validate Egli's theorem with respect to positive extensions — this is because positive extensions of conjunctive sentences completely mimic DPL.

Observation 2.4 (Egli's theorem in DAS)**.**

$$[\![\exists^1\, (\phi \wedge \psi)]\!]^g_+ = [\![\exists^1\, \phi \wedge \psi]\!]^g_+$$

One interesting thing to note is that, even thought DAS is built on a strong Kleene substrate, which doesn't encode linear asymmetries between arguments, nevertheless the system derives a linear bias in the licensing of anaphora. In other words, 1 will be free in the following sentence:

(27) $P\, 1 \wedge \exists^1\, Q\, 1$

This is because, in order to compute the positive extension of a conjunctive sentence, we do relational composition of the positive extensions of the conjuncts, just as in DPL, and relational composition is non-commutative. The linear asymmetry therefore comes from the *dynamics* of passing referential information. It is therefore unnecessary to adopt a proposal such as George's (2007, 2008, 2014), where strong Kleene is incrementalized — at least, not for the purposes of deriving linear asymmetries with anaphora.

Turning to the negative information conveyed by a sentence, it turns out, perhaps surprisingly that DAS doesn't validate Egli's theorem with respect to *negative* extensions.[18] In order to demonstrate this, we'll compute the negative extensions of the sentences in (28), where W stands for *walked in*, and S stands for *sat down*.

[17] N.b., we use $*$ in the meta-language as a wildcard ranging over truth-values.

[18] I'm grateful to [redacted] (p.c.) for pressing me on this point.

(28) a. $\exists^1 (W\,1 \wedge S\,1)$

b. $\exists^1\, W\,1 \wedge S\,1$

Let's start with (28a). Based on the semantics of existential statements, we already know that (28a) will have the input assignment as its negative extension, if its negative extension is non-empty. We compute the conditions under which the negative extension is non-empty in (29); it amounts to the requirement that nobody walked in and sat down.

(29) a. $[\![\exists^1 (W\,1 \wedge S\,1)]\!]^g_-$

b. $= \{\, g \mid [\![\varepsilon^1 (W\,1 \wedge S\,1)]\!]^g_+ = \varnothing \wedge [\![\varepsilon^1 (W\,1 \wedge S\,1)]\!]^g_- \neq \varnothing \,\}$

c. $= \{\, g \mid (I(W) \cap I(S)) = \varnothing \wedge \exists x[x \notin I(W)] \vee \exists x[x \notin I(S)] \,\}$

d. $= \{\, g \mid (I(W) \cap I(S)) = \varnothing \,\}$

Next, we turn to the negative extension of (28b). This is not an existential statement, so we cannot be sure that the negative extension will just be the input assignment, if non-empty. In fact, the output is not guaranteed to be the input, since one of the falsification conditions for strong Kleene conjunction is if the first conjunct is true, and the second is false. We compute the negative extension in (30).

(30) a. $[\![\exists^1\, W\,1 \wedge S\,1]\!]^g_-$

b. $= \{\, i \mid \exists h[h \in [\![\exists^1\, W\,1]\!]^g_- \wedge (*, i) \in [\![S\,1]\!]^h] \,\}$
$\cup \{\, i \mid \exists h[(*, h) \in [\![\exists^1\, W\,1]\!]^g \wedge i \in [\![S\,1]\!]^h_-] \,\}$

c. $= \{\, g \mid I(W) = \varnothing \,\}$
$\cup \{\, g^{[1 \mapsto x]} \mid x \in D \wedge x \in I(W) \wedge x \notin I(S) \,\}$

The negative extension of (28b) is the union of (i) the input assignment, if nobody walked in, otherwise the empty set, and (ii) a set of modified assignments, which map 1 to someone who walked in but didn't sit down. This may seem problematic, since received wisdom is that any indefinite within the scope of negation fails to introduce a DR. Deferring judgement as to whether or not this can be defended on empirical grounds, we have therefore proven that Egli's theorem doesn't hold with respect to negative extensions.[19]

Observation 2.5 (Egli's theorem with respect to negative extensions)**.**

$$[\![\exists^1 (W\,1 \wedge S\,1)]\!]^g_- \neq [\![\exists^1\, W\,1 \wedge S\,1]\!]^g_-$$

[19] An earlier incarnation of this paper developed a logic in which positive closure was built into the semantics of the logical connectives. This had the apparent advantage of validating Egli's theorem with respect to negative information, but came at a cost: (i) the lifting algorithm from strong Kleene to DAS was less straightforward — positive closure had to apply to the *connectives* but not to negation, (ii) the resulting logic failed to validate de Morgan's equivalences.

We'll defend this result more systematically in §3.9, but for the time being it's worth noting that this feature of DAS has an important corollary; unlike in DPL, in DAS de Morgan's equivalences will go through.

Observation 2.6 (de Morgan's equivalences)**.**

$$\neg(\phi \vee \psi) \Leftrightarrow \neg\phi \wedge \neg\psi$$
$$\neg(\phi \wedge \psi) \Leftrightarrow \neg\phi \vee \neg\psi$$

We'll demonstrate this in detail once we turn to disjunction, but as a preview, the negative extension in (30) will be identical to the positive extension of the following bathroom sentence:

(31) Either nobody[1] walked in or they$_1$ didn't sit down. $\neg\exists^1 W 1 \vee \neg S 1$

We'll turn to disjunction and bathroom sentences in the next section.

2.8. Disjunction and bathroom sentences

We'll now turn our attention towards disjunctive sentences, which, as we'll see, will give rise to some additional complexities. Recall that in DAS the entries for the logical operators are derived in a systematic fashion by applying the algorithm in definition 2.9 to the strong Kleene operators. We'll do this now for strong Kleene disjunction ($\vee^s$). First, consider the truth table — strong Kleene disjunction is true if either of the disjuncts are true, and false only if both disjuncts are false; uncertainty projects in the obvious way.

$\vee^s$	1	0	#
1	1	1	1
0	1	0	#
#	1	#	#

Table (2): Disjunction in strong Kleene

Now, as before, we define disjunction in DAS in terms of lifted strong Kleene disjunction.

Definition 2.11 (Disjunction)**.**

$$[\![\phi \vee \psi]\!]^g = \{(t \vee^s u, i) \mid \exists h[(t,h) \in [\![\phi]\!]^g \wedge (u,i) \in [\![\psi]\!]^h]\}$$

Now, let's consider the positive and negative extension of sentences with lifted strong Kleene disjunction separately.

(32) a. $[\![\phi \vee \psi]\!]^g_+ = \{i \mid \exists h[h \in [\![\phi]\!]^g_+ \wedge (*,i) \in [\![\psi]\!]^h]\}$
$\cup\{i \mid \exists h[(*,h) \in [\![\phi]\!]^g \wedge i \in [\![\psi]\!]^h_+]\}$

b. $[\![\phi \vee \psi]\!]^g_- = \{i \mid \exists h[h \in [\![\phi]\!]^g_- \wedge i \in [\![\psi]\!]^h_-]\}$

Since one of the verification conditions for lifted strong Kleene involves passing the negative extension of the first disjunct into the positive extension of the second, we can now immediately account for Partee's bathroom disjunctions.

(33) a. Either there is no^1 bathroom, or it$_1$'s upstairs.

b. $\neg \exists^1 B\, 1 \vee U\, 1$

It will be helpful to start by giving the positive/negative extensions of each of the disjuncts to begin with.

(34) a. $[\![\neg \exists^1 B\, 1]\!]^g_+ = \{ g \mid I(B) = \varnothing \}$

b. $[\![\neg \exists^1 B\, 1]\!]^g_- = \{ g^{[1 \mapsto x]} \mid x \in I(B) \}$

c. $[\![U\, 1]\!]^g_+ = \{ g \mid 1 \in \mathsf{dom}\, g \wedge g_1 \in I(U) \}$

d. $[\![U\, 1]\!]^g_- = \{ g \mid 1 \in \mathsf{dom}\, g \wedge g_1 \notin I(U) \}$

Now to compute the positive extension of the disjunctive sentence, we take the union of the positive extension of the first disjunct, and the result of passing the negative extension of the first disjunct into the second (we only consider this case, since passing the positive/maybe extension of the first disjunct into the second will always result in an empty positive extension, since anaphora won't be licensed):

(35) $[\![\neg \exists^1 B\, 1 \vee U\, 1]\!]^g_+ = \{ g \mid I(B) = \varnothing \} \cup \{ g^{[1 \mapsto x]} \mid x \in I(B) \wedge x \in I(U) \}$

We thereby successfully account for anaphoric licensing in bathroom sentences. The sentence is predicted to be true iff there is no bathroom, or there is a bathroom and it's upstairs. Note that, via de Morgan's, we predict this to be identical to the *negative* extension of the following sentence:

(36) $[\![\exists^1 B\, 1 \wedge \neg U\, 1]\!]^g_- = \{ g \mid I(B) = \varnothing \} \cup \{ g^{[1 \mapsto x]} \mid x \in I(B) \wedge x \in I(U) \}$

An apparent problem with this semantics is that we predict a disjunctive sentence to be externally dynamic, which contradicts the standard assumption in DS — this parallels the issue that arose earlier with conjunction; an existential in a conjunctive sentence can introduce a DR within the scope of negation, depending on how the conjunctive sentence is falsified. In §3, we return to this question, and argue that disjunction *is* in fact externally dynamic by dint of its semantics. A similar issue will arise with implication, which we turn to next.

2.9. Donkey anaphora

We haven't yet said anything about donkey anaphora, as in (37). This is one of the central empirical motivations for classical DS, and DPL-like systems predict strong, universal truth-conditions for sentences like (37).

(37) If anyone[1] is outside, then they$_1$ are happy. $\exists^1\, O\, 1 \rightarrow H\, 1$

In order to consider the predictions made in DAS, let's first consider the semantics for strong Kleene material implication $\rightarrow^s$, repeated below; strong Kleene material implication is true just so long as the either the antecedent is false, or the consequent is true, and false only if the antecedent is true and the consequent is false. Uncertainty projects in the obvious way.

$\rightarrow^s$	1	0	#
1	1	0	#
0	1	1	1
#	1	#	#

Table (3): Material implication in strong Kleene

We can derive the meaning for the conditional operator in DAS by the same procedure as before; namely, we lift strong Kleene implication into a dynamic setting. Skipping over the details, we end up with the following positive and negative extensions for implicational sentences in DAS.

(38) a. $$[\![\phi \rightarrow \psi]\!]^g_+ = \{\, i \mid \exists h[h \in [\![\phi]\!]^g_- \wedge (*, i) \in [\![\psi]\!]^h]\,\} \cup \{\, i \mid \exists h[(*, h) \in [\![\phi]\!]^g \wedge i \in [\![\psi]\!]^h_+]\,\}$$

b. $$[\![\phi \rightarrow \psi]\!]^g_- = \{\, i \mid \exists h[h \in [\![\phi]\!]^g_+ \wedge i \in [\![\phi]\!]^g_-]\,\}$$

If we apply this semantics to a donkey sentence we predict weak, existential truth-conditions. This is easiest to see if we compute the positive extension of a donkey sentence.

(39) a. If anyone[1] is outside, then they$_1$ are happy.

b. $\exists^1\, O\, 1 \rightarrow H\, 1$

Consider first the positive/negative extensions of the antecedent (40) and consequent (41):

(40) a. $[\![\exists^1\ O\ 1]\!]^g_+ = \{\, g^{[1 \mapsto x]} \mid x \in I(O)\,\}$

b. $[\![\exists^1\ O\ 1]\!]^g_- = \{\, g \mid I(O) = \varnothing\,\}$

(41) a. $[\![H\ 1]\!]^g_+ = \{\, g \mid 1 \in \mathsf{dom}\ g \wedge g_1 \in I(H)\,\}$

b. $[\![H\ 1]\!]^g_- = \{\, g \mid 1 \in \mathsf{dom}\ g \wedge g_1 \notin I(H)\,\}$

We can now compute the positive extension of the conditional sentence as in (42). Note that the positive extension will be non-empty if either nobody is outside, or there is at least one person who is both outside and happy.

(42) $$[\![\exists^1\ O\ 1 \rightarrow H\ 1]\!]^g_+ = \{\, g^{[1\mapsto x]} \mid x \in I(O) \wedge x \in I(H) \,\} \cup \{\, g \mid I(O) = \varnothing \,\}$$

What about the negative extension? This will be non-empty iff someone is outside and not happy. If non-empty, it outputs a set of modified assignments which map 1 to someone who is outside and not happy.

(43) $$[\![\exists^1\ O\ 1 \rightarrow H\ 1]\!]^g_- = \{\, g^{[1\mapsto x]} \mid x \in I(O) \wedge x \notin I(H) \,\}$$

This doesn't seem to match our intuitions regarding the truth-conditions of the sentence under consideration, which imposes a stronger, universal requirement. Concretely, in a *mixed* scenario, in which someone is here and unhappy, and someone else is here and happy, the sentence is predicted to be *true*. The falsity conditions, on the other hand, seem reasonable. As is well-known, in fact both existential and universal readings of donkey sentences are attested (Chierchia 1995, Kanazawa 1994, Champollion, Bumford & Henderson 2019); our semantics derives the existential reading, and we need to do something extra to derive the universal reading. Our theory therefore diverges sharply from DPL-like theories, which derive the universal reading as basic. How to capture existential vs. universal readings is a thorny issue, and there at least exist many proposals which assume that existential readings should be generated in the semantics (see, e.g., Chierchia 1995, Kanazawa 1994, Champollion, Bumford & Henderson 2019), and therefore we leave a more thorough exploration of donkey anaphora in DAS to future work. In §B I sketch one possible way to derive the universal reading, via independently motivated pragmatic strengthening mechanisms.

One final thing to note is that, just as in the discussion of disjunctive sentences, we predict conditional sentences to be externally dynamic, which contradicts the standard assumption in DS. We'll turn to the question of how to reinstate accessibility facts in the next question.

3. Accessibility and pragmatics

3.1. Accessibility issues

There seems to be a problem for our entries for complex sentences, involving accessibility. We'll illustrate this by giving a concrete example — consider the following disjunctive sentence, alongside its proposed translation.

(44) Either this house hasn't been renovated, or there's a[1] bathroom. $\neg\,(R\ h) \vee (\exists^1 B\ 1)$

Suppose that, in the model, there is exactly one bathroom b, so $I(B) = \{\, b \,\}$, and furthermore this house has been renovated (so $I(h) \in R$). In such a model, we predict anaphora to be licensed in (45). This is because the positive extension of the disjunctive sentence will output modified assignments which map 1 to a bathroom.

(45) Either this house hasn't been renovated, or there's a^1 bathroom.
It$_1$'s upstairs.

On the basis of similar observations, Groenendijk & Stokhof (1991) give a semantics for disjunctions in DPL that is *externally static*. I.e., the impossibility of anaphora in (45) is built directly into the entry for disjunction.

A similar problem arises for our entry for implication; suppose that in the model, again, there is a bathroom and this house has been renovated. We predict that anaphora should be possible, however this does not seem to be the case as illustrated in (46). On the basis of similar data, Groenendijk & Stokhof (1991) also give a semantics for implication in DPL that is *externally static*.

(46) If this house has been renovated, then there's a^1 bathroom.
It$_1$'s upstairs.

In the following, we'll discuss two problems for building externally staticity into the semantics, focusing on disjunction — in §3.7, we discuss a problem specific to disjunctive sentences, and in §3.3 we discuss a more general problem for Groenendijk & Stokhof, which we claim reveals something about what is responsible for cases of external staticity.

3.2. Problem 1: Stone disjunctions

As Groenendijk & Stokhof observe, the DPL entry for disjunction fails to capture *Stone disjunctions*, as illustrated in (47) (Stone 1992). This data would seem to clearly indicate that disjunction is externally dynamic, and that something else is responsible for the impossibility of anaphora in (45).

(47) Either a^1 philosopher is in the audience or a^1 linguist is.
(Either way) I hope she$_1$ enjoys it.

In fact, in order to account for Stone disjunctions, Groenendijk & Stokhof (1991) define a novel, externally-dynamic connective, which they dub *program disjunction*, and suggest that natural language disjunction can either express DPL disjunction, or program disjunction. Conceptually, this is clearly an undesirable move, and it begs the question of what factors regulate this putative ambiguity. In DAS, as we'll see, there's no need to posit an ambiguity here — Stone disjunctions will follow straightforwardly from the DAS entry for disjunction, just so long as the disjuncts contain co-indexed indefinites.

3.3. Problem 2: Rothschild's observation

Rothschild observes that, in a discourse with an asserted disjunctive sentence, if the truth of the disjunct containing an indefinite is later contextually entailed, anaphora becomes possible. Consider the discourse in (48). Suppose that the director of a play (A) has lost track of time, and doesn't know what day it is. The director is certain, however, that on Saturday and Sunday, different critics will be in the audience, and utters the disjunctive sentence in (48a). A's assistant

(B), knows what day it is, and utters the sentence in (49b), which contextually entails the second disjunct. Subsequently, anaphora is licensed in (48c), since the information that a^1 *critic is watching our play* has entered into the common ground.

(48) a. A: Either it's a weekday, or a^1 critic is watching our play.

b. B: It's Saturday.

c. A: They_1'd better give us a good review.

This data is mysterious for a theory such as DPL, which builds external staticity into the semantics of disjunction. Furthermore, this phenomena does not only concern disjunction, but is far more general — we can construct a similar example involving a conditional sentence.

(49) a. A: If it's the weekend, then a^1 critic is watching our play.

b. B: It's Saturday.

c. A: They_1'd better give us a good review.

What's going on here? Following Rothschild's suggestion we'll pursue the idea that complex sentences can give the illusion of external staticity, given the conversational backgrounds against which they can be felicitously uttered. The data will fall out once we make concrete the pragmatic component of the theory (an orthodox extension of a Stalnakerian pragmatics), and supplement the analysis with some independently motivated pragmatic constraints on the utterance of complex sentences. In the following, we'll make concrete our assumptions regarding the pragmatic components, before formalizing our analysis.

3.4. Intensionalization

In order to formalize the account, we'll need to intensionalize DAS — fortunately, this is almost completely mechanical; we add a finite non-empty set of *possible worlds* W to the model, add a world parameter to the interpretation function, and relativize I to the world of evaluation. In an intensional setting, sentences will return world/truth-value/assignment *tuples*, rather that world assignment pairs. This is illustrated below for a simple atomic sentence. Everything else remains as before, except we'll assume that the positive/negative extension in an intensional setting is a set of world-assignment pairs (rather than just assignments).

(50) a. $[\![P\ 1]\!]^{w,g} = \{\, (\partial\,(n \in \text{dom } g) \wedge g_n \in I_w(P), w, g) \,\}$

b. $[\![P\ 1]\!]^{w,g}_{+} = \{\, (w, g) \mid \partial\,(n \in \text{dom } g) \wedge g_n \in I_w(P) \,\}$

c. $[\![P\ 1]\!]^{w,g}_{-} = \{\, (w, g) \mid \partial\,(n \in \text{dom } g) \wedge g_n \notin I_w(P) \,\}$

We'll also outline a simple Heimian/Stalnakerian pragmatics in the next section, alongside a rule of assertion.

3.5. Pragmatic assumptions

We'll assume a relatively standard dynamic notion of an information state, consisting of a set of world-assignment pairs, as in definition 3.1.[20] Such information states can track relative certainty regarding both worldly and referential information. Since assignments are partial, it's natural to treat the initial information state as the product of logical space, and the initial assignment — this represents a scenario in which nothing is known, and nothing has been said.

Definition 3.1 (Information state)**.** An *information state* c is a set of world-assignment pairs. Where:

- $c_{\top}$, the initial information state, is defined as: $W \times \{ g_{\top} \}$.
- $c_{\varnothing}$, the absurd information state is the empty set $\varnothing$

Now we define an *update* operation to model the effect on a context (which we model as an information state) of asserting a sentence; given a sentence ϕ, update maps information states to information states. Since DAS is distributive,[21] much like DPL, update does some work — namely, it computes the positive extension of the sentence at every point in the information state, and gathers up the results. As usual, update is assumed to be subject to Stalnaker's *bridge principle* (von Fintel 2008), generalized to information states in the obvious way — for update to be defined, the sentence must be either true or false at every *point* in the input context.

Definition 3.2 (Update)**.**

$$c[\phi] := \begin{cases} \bigcup\limits_{(w,g)\in c} [\![\phi]\!]_{+}^{w,g} & \forall (w,g) \in c[[\![\phi]\!]_{+}^{w,g} \neq \varnothing \vee [\![\phi]\!]_{-}^{w,g} \neq \varnothing] \\ \varnothing & \text{otherwise} \end{cases}$$

We get Heim's (1991) *familiarity presupposition* for free, from the definedness conditions on atomic sentences, in combination with the universal requirement of bridge, i.e., update of an information state c with a sentence with a free variable n will only be defined if n is defined for *every* assignment in the information state. We say that a variable n is *familiar* in a context c, iff n is in the domain of every assignment, s.t., $(*, g) \in c$.[22] It's easy to see that an utterance of a sentence with an indefinite will result in an information state that satisfies the presupposition induced by matching free variable.

[20] This corresponds fairly directly to Heim's (1982) notion of a *file*.

[21] This means, if defined, the result of updating an information state c with a sentence ϕ is equivalent to updating each *point* in ϕ with ϕ, and gathering up the results. See van Benthem (1986), and Rothschild & Yalcin (2016) for recent discussion.

[22] As it stands, our entry for existential quantification will simply overwrite information associated with a matching assignment in the input context, which is often taken to be an undesirable conequence (see, e.g., Groenendijk, Stokhof & Veltman 1996). See §3.7 for further discussion of this issue.

3.6. Deriving external staticity

We're now in a position to account for some of the behaviour observed for disjunctive sentences in §2.8. The first thing to observe is that disjunctive sentences place a requirement on the context — an utterance of a sentence of the form "P or Q" is only felicitous if both P and Q are *real* possibilities, i.e., the context shouldn't entail the truth/falsity of either of the disjuncts.[23]

(51) Context: *it's common ground that someone was in the audience.*
Either someone was in the audience or the event was a disaster.

We can use this fact to account for the apparent external staticity of disjunction. Consider the following space of logical possibilities:

- w_{ad}: a was in the audience, and the event was a disaster.
- $w_{a\neg d}$: a was in the audience, and the event wasn't a disaster.
- $w_{\varnothing d}$: nobody was in the audience, and the event was a disaster.
- $w_{\varnothing\neg d}$: nobody was in the audience, and the event wasn't a disaster.

And consider the sentence under consideration, and a simplified Logical Form:

(52) a. Either someone[1] was in the audience, or the event was a disaster.
b. $\exists^1\, A\, 1 \vee D\, e$

Let's first consider the positive extension of the disjunctive sentence, which we compute by considering the different verification conditions of strong Kleene disjunction, lifted into a dynamic setting, as usual. This is just all the assignments in the positive extension of the first disjunct, together with the result of passing the positive/negative/maybe extension of the first disjunct into the second and gathering up the (positive) results.

(53) $$[\![\exists^1\, A\, 1 \vee D\, e]\!]^g_+ = \{\, (w, g^{[1\mapsto x]}) \mid x \in I_w(A)\,\} \\ \cup \{\, (w, g) \mid I_w(A) = \varnothing \wedge I_w(e) \in I_w(D)\,\}$$

We can now consider the result of updating the initial information state with the disjunctive sentence. Note that the bridge principle is trivially satisfied, since the sentence doesn't contain any free variables. We simply dispense with any points not in the positive extension of the sentence, resulting in the following updated context.

[23] I remain neutral on the nature of this requirement, but it can plausibly be derived as a *manner* implicature — see, e.g., Meyer (2016) for discussion.

$$(54) \quad \left\{\begin{array}{l}(w_{ad}, g_{\top}),\\(w_{a\neg d}, g_{\top}),\\(w_{\varnothing d}, g_{\top}),\\(w_{\varnothing\neg d}, g_{\top}),\end{array}\right\}[\exists^1 A\ 1 \vee D\ e] = \left\{\begin{array}{l}(w_{ad}, [1 \mapsto a]),\\(w_{a\neg d}, [1 \mapsto a],\\(w_{\varnothing d}, g_{\top}),\end{array}\right\}$$

Note, crucially, that the resulting information state is one in which 1 is *not familiar*! This means that the presupposition of a subsequent sentence with a matching free variable won't be satisfied. This derives the (apparent) external staticity, in cases where the independently motivated requirement that the disjuncts are real possibilities is satisfied.[24]

(55) *Context: total ignorance*
Either someone[1] was in the audience, or the event was a disaster. # She$_1$ enjoyed it.

This account correctly captures Rothschild's observation: an intermediate assertion can eliminate the world-assignment pair $(w_{\varnothing}, g_{\top})$, thus rendering 1 familiar.

(56) *Context: total ignorance*

a. Either someone[1] was in the audience, or the event was a disaster.

b. (Actually) the event wasn't a disaster.

c. So, I hope she$_1$ enjoyed it.

What if we entertain an information state identical to the initial state, only with this point removed? The result is an information state which entails that *either a was in the audience, or the event wasn't a disaster*.

$$(57) \quad c' := \left\{\begin{array}{l}(w_{ad}, g_{\top}),\\(w_{a\neg d}, g_{\top}),\\(w_{\varnothing\neg d}, g_{\top}),\end{array}\right\}$$

Updating this context with the disjunctive sentence results in just those worlds in which a was in the audience, paired with assignments mapping 1 to a. In other words, an update of $c'[\exists^1 A\ 1 \vee D\ e]$ is contextually equivalent to an update by just the first disjunct $c'[\exists^1 A\ 1]$. We assume that uttering a disjunctive sentence $\phi \vee \psi$ is odd, if $\phi \vee \psi$ is contextually equivalent to a simpler alternative (i.e., ϕ, or ψ). This can plausibly be derived as a *manner* implicature.

I'm optimistic that this general style of explanation can be extended to the (apparent) external staticity of conditional sentences. but this is complicated by the fact that material implication is undoubtedly not a realistic semantic proposal for conditional sentences of English. I leave a thorough exploration of this issue to future work.

[24]The explanation also goes through for cases in which the indefinite is in the second disjunct.

3.7. Accounting for Stone disjunctions

Stone disjunctions are not particularly problematic for DAS. The pragmatic requirement on disjunctive assertions allows for subsequent anaphora in such cases. To illustrate, consider the following:

(58) Either a[1] linguist is here, or a[1] philosopher is.
$\exists^1 (L\,1 \wedge H\,1) \vee \exists^1 (P\,1 \wedge H\,1)$

Let's begin by considering the positive/negative extensions of each disjunct.

(59) A[1] linguist is here
a. $[\![\exists^1 (L\,1 \wedge H\,1)]\!]^g_+ = \{\, g^{[1\to x]} \mid x \in I(L) \wedge x \in I(H) \,\}$
b. $[\![\exists^1 (L\,1 \wedge H\,1)]\!]^g_- = \{\, g \mid (I(L) \cap I(H)) = \varnothing \,\}$

(60) A[1] philosopher is here
a. $[\![\exists^1 (P\,1 \wedge H\,1)]\!]^g_+ = \{\, g^{[1\to x]} \mid x \in I(P) \wedge x \in I(H) \,\}$
b. $[\![\exists^1 (P\,1 \wedge H\,1)]\!]^g_- = \{\, g \mid (I(P) \cap I(H)) = \varnothing \,\}$

In order to compute the positive extension of the Stone disjunction in (58), we go through each of the verification conditions of strong Kleene disjunction, and take the union of the results. One important thing to note here is that, since Stone disjunctions involve existentials with matching variables, we need to say say something concrete about the behaviour of the existential if its variable is already defined at the input assignment. There are two possibilities within the current setting: either the existential overwrites the existing information associated with the variable, in a procedure alternately described as *destructive update/downdate* (see, e.g., Groenendijk, Stokhof & Veltman 1996 for discussion), or we modify the entry for existentials in order to rule out overwriting. For concreteness, we go the second route, and adopt the "guarded" interpretation for DPL existential quantification in definition 3.3, following van den Berg 1996 (recall that this underlies the semantics of existential quantification in DAS). This semantics is the same as before, except the output is maybe-tagged if the variable is already defined at the input assignment.[25]

Definition 3.3 (Guarded DPL existential quantification in DAS (after van den Berg 1996)).

$$[\![\varepsilon^n\ \phi]\!]^g := \begin{cases} \bigcup\limits_{x\in D} \{\, ([\![\phi]\!]^{g^{[1\mapsto x]}}, g^{[1\mapsto x]}) \,\} & n \notin \mathsf{dom}\ g \\ \{\, (\#, g) \,\} & \text{else} \end{cases}$$

Due to guarded existential quantification, if the first disjunct is true, the second disjunct is *always* undefined in its local context, as in (62a). This simplifies the computation of each of the verification conditions of strong Kleene disjunction. If the first disjunct is *false* however, the

[25]Note that, since Stone disjunctions necessarily involve *co-indexed* indefinites, syntactic constraint on *index re-use*, such as Heim's 1982 *novelty condition*, are incompatible with the proposal. In fact, it's rather difficult to imagine an account of Stone disjunctions which *doesn't* make use of co-indexed indefinites.

existential fails to introduce a DR due to positive closure, and the second disjunct can be true in its local context, as in (62b) — in fact, it must be true, for the disjunctive sentence to be dynamically verified.[26]

(62) a. first disjunct true; second undefined
$= \{ i \mid \exists h[h \in [\![\exists^1 (P\,1 \wedge H\,1)]\!]^g_+ \wedge i \in [\![\exists^1 (P\,1 \wedge H\,1)]\!]^h_u] \}$
$= \{ g^{[1\to x]} \mid x \in I(L) \wedge x \in I(H) \}$

b. first disjunct false; second true
$= \{ i \mid \exists h[h \in [\![\exists^1 (P\,1 \wedge H\,1)]\!]^g_+ \wedge i \in [\![\exists^1 (P\,1 \wedge H\,1)]\!]^h_u] \}$
$= \{ g^{[1\to x]} \mid (I(L) \cap I(H)) = \varnothing \wedge x \in I(P) \wedge x \in I(H) \}$

The union of the two different ways of dynamically verifying the disjunctive sentence (63) gives us its positive extension. The salient point to note here is that the output set *only* contains assignments at which 1 is defined.

(63) $$[\![\exists^1 (L\,1 \wedge H\,1) \vee \exists^1 (P\,1 \wedge H\,1)]\!]^g_+ = \{ g^{[1\to x]} \mid x \in I(L) \wedge x \in I(H) \} \cup \{ g^{[1\to x]} \mid (I(L) \cap I(H)) = \varnothing \wedge x \in I(P) \wedge x \in I(H) \}$$

Let's illustrate concretely how this licenses a subsequent anaphoric pronoun in context. Consider the following logical space, where subscripts indicate, exhaustively, who is here (l, a linguist, and p, a philosopher): $W := \{ w_{lp}, w_l, w_p, w_\varnothing \}$. Updating the initial information state with the Stone disjunction results in an information state where the familiarity presupposition induced by a matching free variable is satisfied, due to introduction of a DR that is either a linguist or a philosopher.

(64) $$\left\{ \begin{matrix} (w_{lp}, g_\top) \\ (w_l, g_\top), \\ (w_p, g_\top), \\ (w_\varnothing, g_\top), \end{matrix} \right\} [(\exists^1 (L\,1 \wedge H\,1) \vee \exists^1 (P\,1 \wedge H\,1)] = \left\{ \begin{matrix} (w_{lp}, [1 \mapsto l]) \\ (w_l, [1 \mapsto l]), \\ (w_p, [1 \mapsto p]) \end{matrix} \right\}$$

To my knowledge, this consistutes the first analysis of disjunction in dynamic semantics which straightforwardly captures both bathroom disjunctions and Stone disjunctions in a straightforward fashion; certainly, it's a marked improvement over DPL, in which Stone disjunctions are captured by positing an ad-hoc ambiguity in the semantics of disjunction.[27]

[26] Note that guarded existential quantification does however correctly rule out conjunctive sentences with co-indexed indefinites in each conjunct, such as (61).

(61) # A^1 linguist is here and a^1 philosopher is here.

Guarded existential quantification predicts that this sentence can only ever be false or undefined; verifying conjunction requires both conjuncts to be true.

[27] One slightly odd prediction, of the analysis is that world w_{lp} is paired with a *linguist* DR only, due to guarded existential quantification, but this doesn't make any obviously bad predictions, since disjunctive sentences typically carry a *not and* scalar inference, which presumably eliminates this world from the output context.

3.8. Internal staticity and logical independence

Groenendijk & Stokhof (1991) observe that disjunction appears to be internally static; an indefinite in an initial disjunct can't license anaphora in a subsequent disjunct.

(65) #Either someone[1] is in the audience, or they$_1$'re sitting down.

Similarly to the explanation they provide for cases of apparent external staticity, Groenendijk & Stokhof build this behaviour directly into the semantics of disjunctive sentences — no referential information is passed from the first disjunct into the second (or vice versa).[28] Our discussion of bathroom sentences already showed that this move was untenable — there, it was necessary to say that referential information *is* passed from the first disjunct into the second; concretely, the *negative* referential information associated with the first disjunct could license a pronoun in the second. This leaves the impossibility of anaphora in (65) as something of a mystery.

As background to our proposal, we'll first consider Simons's (1996) explanation for why disjunction is internally static. Simons suggests that the reason that anaphora is impossible in (65) is not due to the dynamics of disjunction, but because the pronoun in the second disjunct is interpreted as a covert definite description (i.e., via the "e-type" strategy; see, e.g., Evans 1977, Heim 1990, Elbourne 2005 for different versions of this conjecture). On this view, the pronoun stands in for the description *the person in the audience*, as in (67). (67) is infelicitous, therefore Simons suggests that we (i) provide a principled explanation for the infelicity of (67), and (ii) explain the impossibility of anaphora in (65) on the basis of (67), assuming an e-type strategy for the pronoun in the second disjunct.

(67) #Either someone is in the audience, or [the person in the audience] is sitting down.

So, why is (67) infelicious? To start with, Hurford (1974) famously observed that disjunctive sentences are generally infelicitous if one disjunct entails the other (see also Gazdar 1979). This general principle is known as Hurford's constraint (HC) — it can be illustrated by considering a minimal variation of (68).

(68) #Either someone is in the audience, or someone in the audience is sitting down.

HC can be extended to (67) if we reformulate the constraint in a way that takes into account the possibility of presupposition: a disjunctive sentence is infelicitous if one of the disjuncts *Strawson entails* the other.[29] This is because, the second disjunct presupposes that *a (unique) person is in the audience*. Assuming that the presupposition is satisfied, the second disjunct entails the first.

[28] This can be seen clearly by inspecting the DPL entry for disjunction, repeated in (66). Note that *both* disjuncts are interpreted relative to the same input assignment g.

(66) $[\![\phi \vee \psi]\!]^g_{DPL} = \{\, g \mid ([\![\phi]\!]^g_{DPL} \cup [\![\psi]\!]^g) \neq \varnothing \,\}$

[29] Informally, a sentence ϕ Strawson entails a sentence ψ, if, when the presuppositions of ϕ are satisfied, ϕ entails ψ (following the definition of von Fintel 1999).

Although the basic idea seems intuitively on the right track, there are a number of reasons to find the precise formulation of the analysis dissatisfying. In order to account for why the pronoun in the second disjunct *must* receive an e-type interpretation, rather than simply being interpreted as a variable, Simons *assumes* a dynamic semantics with an internally static semantics for disjunction (Simons's analysis is framed in terms of Discourse Representation Theory (DRT), but could be reformulated in terms of, e.g., DPL); this is, however, exactly what we'd like to explain on the basis of some independent principle. Furthermore, the e-type theory of pronoun interpretation is generally seen as an *alternative* to DS (Heim 1990) — an account such as that of Simons, which requires both pronouns which denote variables *and* e-type pronouns is less parsimonious than a theory which only makes use of one of these mechanisms. We'll therefore develop an alternative analysis consistent with the assumptions of DAS — namely, disjunction is internally dynamic, and pronouns denote variables.

Consider the translation of (65) in DAS, given in (69). Now, we can ask ourselves — under what conditions could the second disjunct in (69) have a non-empty positive extension? This is predicted to only be possible if the first disjunct is *true*; if the first disjunct is false or undefined, then due to positive closure, it doesn't introduce a DR, and therefore the variable in the second disjunct will induce undefinedness. It follows that, even context in which the second disjunct is true, will be one in which the first is also true. Our suggestion is as to why anaphora is impossible in (65), is that the representation violates a formulation of HC that takes into account the dynamics of disjunction, as stated in (70).

(69) $\exists^1 A\,1 \vee S\,1$ (Either someone[1] is in the audience, or they$_1$'re sitting down)

(70) *Dynamic Hurford's constraint*
$\ulcorner\phi \vee \psi\urcorner$ is odd if $[\![\neg\,\phi \wedge \psi]\!]^g_+ = \varnothing \vee [\![\phi \wedge \neg\,\psi]\!]^g_+ = \varnothing, \forall g$

(65) is independently ruled out by dynamic HC, since $[\![\neg\,\exists^1 A\,1 \wedge S\,1]\!]^g_+ = \varnothing, \forall g$. As the reader can verify for themselves, (70) also rules out classical HC violations such as (68), and rules *in* bathroom sentences. It wasn't possible to take an existing formulation HC "off the shelf" so to speak, since existing formulations generally don't take into account the possibility of anaphoric dependencies between the disjuncts. One avenue for future research is a consideration of the status of (70) in light of Singh's (2008) attempt to reduce HC to incremental redundancy.

3.9. Negated conjunctive sentences

We'll finish this section by noting an apparent problem for DAS involving anaphora in conjunctive sentences, and show that the basic explanation for the internal staticity of disjunction can be extended to other problematic case. Consider the negated conjunctive sentence in (71), alongside its DAS translation:

(71) a. #It's not the case that [nobody[1] is in the audience and they$_1$'re sitting down].

b. $\neg\,(\neg\,\exists^1 A\,1 \wedge S\,1)$

Clearly, anaphora is *not* possible here — a fact that is easily captured in, e.g., DPL, due to the fact that negation, in general, roofs the dynamic scope of an indefinite. In DAS, perhaps surprisingly, anaphora is predicted to be possible. To see why, first recall that the positive extension of $\neg\,\phi$ is simply the negative extension of ϕ. Let's therefore compute the negative extension of the contained sentence. We'll begin by considering the positive/negative extensions of each conjunct:

(72) Nobody[1] is in the audience.

a. $[\![\neg\,\exists^1\,A\,1]\!]^g_+ = \{\,g \mid I(A) = \varnothing\,\}$

b. $[\![\neg\,\exists^1\,A\,1]\!]^g_- = \{\,g^{[1\mapsto x]} \mid x \in I(A)\,\}$

(73) They[1]'re sitting down.

a. $[\![S\,1]\!]^g_+ = \{\,g \mid 1 \in \mathsf{dom}\,g \wedge g_1 \in I(S)\,\}$

b. $[\![S\,1]\!]^g_- = \{\,g \mid 1 \in \mathsf{dom}\,g \wedge g_1 \notin I(S)\,\}$

We now consider the different ways of dynamically *falsifying* a conjunctive sentence, according to the strong Kleene interpretation schema. If the first conjunct is true (or maybe), the second will always have an empty negative extension, since the pronoun will lack an antecedent, leaving us to consider cases in which the first conjunct is false.

(74) first conjunct false, second true
$= \{\,g^{[1\mapsto x]} \mid x \in I(A) \wedge x \in I(S)\,\}$

(75) first conjunct false, second false
$= \{\,g^{[1\mapsto x]} \mid x \in I(A) \wedge x \notin (S)\,\}$

The negative extension of the contained conjunctive sentence, and hence the positive extension of the whole negative sentence is therefore non-empty — it's simply the union of these two cases:

(76) $[\![\neg\,(\neg\,\exists^1\,A\,1 \wedge S\,1)]\!]^g_+ = \{\,g^{[1\mapsto x]} \mid x \in I(A)\,\}$

This seems like a bad result, since anaphora is clearly *not* possible in this instance. Note however that that (71) is semantically *equivalent* to a positive disjunctive sentence, as illustrated below (an instance of de Morgan's laws). This should give us a clue as to why anaphora is not possible — we ruled out anaphora in the disjunctive sentence via an independently motivated pragmatic constraint.

(77) $\neg\,(\neg\,\exists^1\,A\,1 \wedge S\,1) \Leftrightarrow \neg\,\neg\,\exists^1\,A\,1 \vee \neg\,S\,1 \Leftrightarrow \exists^1\,A\,1 \vee \neg\,S\,1$

It seems like negated conjunctive sentences are subject to much the same pragmatic constraints as corresponding disjunctions of negative sentences. For example, an utterance of "not [P and Q]" is infelicitous unless "not P" and "not Q" are *real possibilities* — again, this follows plausibly from considerations of *Manner*. Pertinent to our concerns here, it seems that negated conjunctions are subject to something like HC; in a sentence of the form "not [P and Q]" is either conjunct entails the other, the sentence is odd, as illustrated by the following sentence.

(78) # It's not true [that someone is in the audience and someone in the audience is sitting down].

We'd therefore like to suggest that the impossibility of anaphora in (71) follows from the fact that, if the negation of the first conjunct is *false*, then the negation of the second conjunct always has an empty positive extension. This violates dynamic HC, applied to negated conjunctions via de Morgan's equivalence.

Via similar reasoning, we can also tie up a loose end that emerged in the discussion of Egli's theorem. We observed that Egli's theorem, in DAS, in fact *doesn't* go through in the negative dimension; a negated conjunctive sentence of the following kind can introduce a DR depending on how the conjunctive sentence is falsified.

(79) It's not the case [that someone^1 walked in and they$_1$ sat down]

A subsequent anaphoric pronoun is independently ruled out by the independently motivated requirement that an assertion of (79) requires *nobody walked in* and *they didn't sit down* to be real possibilities (i.e., the negation of each conjunct). A licit context updated by (79) will therefore fail to satisfy the familiarity presupposition of a subsequent co-indexed pronoun. This makes arguably a good prediction — if the truth of the first conjunct is subsequently contextually entailed, then anaphora should become possible. The following discourse is intended to illustrate that this prediction is borne out.

(80) a. A: It's not the case that (both) someone^1 is in the audience *and* they have a question.

b. B: Well, the auditorium isn't empty. I hope they$_1$ enjoyed the lecture.

4. Extensions

4.1. Uniqueness and universal inferences

An apparent problem with the current system is that it fails to capture Krahmer & Muskens's (1995) intuition that bathroom sentences have strong, universal truth-conditions, as mentioned earlier in the paper. What is responsible is that the logic we have developed here derives weak, existential truth-conditions for donkey anaphora, and this carries over to bathroom sentences.

One thing to observe is that weak readings of bathroom sentences are in fact attested, so the fact that our theory can at least generate this reading should not count against it. Presumably, whatever mechanism is responsible for deriving strong readings for donkey anaphora could derive strong readings for bathroom sentences too. The weak reading is illustrated in the following example:

(81) Everyone who [either has no^1 credit card or paid with it$_1$] has left the restaurant.

Clearly, anyone with at least one credit card and paid with it has left — whether or not they have other credit cards which they did/didn't pay with is irrelevant to the truth of the sentence. In

§B we explore the possibility of a general mechanism for strengthening weak, existential readings into universal readings in Upward Entailing (UE) environments.

As for Gotham's claim that double negation and disjunctive sentences are associated with a uniqueness inference, this is directly counter-exemplified in (81) for bathroom sentences; for double-negation, i'm skeptical that uniqueness is the right characterization of the facts, [redacted] (p.c.) notes that an indefinite under double negation also licenses *maximal* plural anaphora:

(82) Logan doesn't have no^1 credit card. They$_1$'re on the table.

The conditions governing putative uniqueness inferences are poorly understood, and the judgements are not completely stable. We leave a further investigation of these facts to future work.

4.2. Related work

There are a number of proposals which directly inspired the current work, such as Krahmer & Muskens's (1995) *double negation* DRT and Gotham's (2019) work on the status of double negation and disjunction in DPL. Although these proposals clearly relate to the current work — especially Krahmer & Muskens's bivalent semantics — these are not direct competitors, since they rely on stipulated dynamic connectives, as in orthodox DS.

Probably the most directly relevant is Rothschild 2017, which aims to give a unified account of presupposition projection and anaphora in terms of a trivalent semantics for the logical operators. Rothschild departs much further from standard dynamic semantics than we do here, and makes one crucial assumption that we can do without — in order to capture, e.g., bathroom sentences, Rothschild assumes the free insertion of classically transparent conjuncts. The nature of this insertion process is somewhat mysterious. Furthermore, in order to capture linear asymmetries, Rothschild notes that he would have to adopt an incrementalized version of the strong Kleene connectives (see George 2007, 2008, 2014). In DAS, simple strong Kleene alongside the logic of referential information passing derives linear asymmetries straightforwardly.

Similarly, Mandelkern (2020) develops an extremely interesting system he dubs *pseudo-dynamics*, which seems to make largely the same predictions as DAS. Unlike DAS however, pseudo-dynamics is static, and rests on an eliminative notion of update. Although I don't discuss the proposal in depth here, i'll simply note that there are some conceptual issues for *pseudo-dynamics* that DAS skirts — for example, in pseudo-dynamics indefinites carry a disjunctive presupposition, which unlike other presuppositions, is (somewhat mysteriously) assumed to be automatically accommodated. In DAS, on the other hand, the same result is achieved via positive closure, which simply ensures that DRS are only introduced in the positive extension of a given sentence. Nothing special need be said about the logic of presupposition.

4.3. Conclusion

In this paper, we've developed an alternative dynamic logic for anaphora: DAS, which improves on competing accounts in a number of ways. DAS essentially layers the mechanics of referential information passing on top of a trivalent substrate, based on the logic of Strong Kleene; the logic is *predictive*, in the sense that a strong Kleene semantics can be derived for any logical operator via the logic of uncertainty. I showed that, as well addressing a prominent conceptual objection to DS, DAS very much improves the empirical coverage of orthodox dynamic theories.

It's important to emphasize that the predictive nature of DAS came at an apparent cost — certain accessibility generalizations observed by Groenendijk & Stokhof (1991) no longer fall out. The narrative that this paper develops is as follows: in developing a logic of anaphora, the literature was essentially mistaken in taking the data completely at face value. This is a lesson that has largely been learned in other domains, such as the study of implicature — going back to the foundational work of Grice, it's generally been recognized that, in order to maintain a parsimonious logic, due care needs to be taken to address the role of pragmatic factors. I've attempted to show that, in taking the pragmatic component seriously, we can control for many confounding factors involved in constraining anaphoric possibilities. Once controlled for, the result is a considerably more parsimonious and explanatory logic of anaphora.

I take DAS to be, not the final word, but a *starting point* for a new, predictive approach to the dynamics of anaphora, using the logic of strong Kleene as a foundation. An major omission in the current work is any discussion of first-order or generalized quantification. The logic of strong Kleene can be generalized to quantification (see, e.g., Krahmer 1998, George 2008, 2014), so an obvious avenue for future research is the extent to which we can give a predictive semantics for determiners using a similar method to the one outlined for the logical connectives. There are other possible extensions which can and should be explored, to phenomena within the purview of DS more broadly construed, such as quantificational subordination and discourse plurals. I'm optimistic that taking a *predictive* approach as a starting point will help illuminate the role of semantics vs. pragmatics in the explanation of linguistic phenomena such as anaphora.

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A. Compositional fragment

The basic tenets of DAS can easily be recast as a compositional fragment of English. A straightforward advantage of this presentation is that the truth-functional operators can be treated semantically as functions from truth values to truth values, and lifted into a dynamic setting "on the fly" via a principled inventory of type shifters.

Rather than furnishing the interpretation function with an assignment parameter, we'll assume that sentences simply denote *dynamic propositions*, i.e., functions from assignments to sets of truth-value assignment pairs. This will be useful when it comes time to give an explicit treatment of the lifting procedure in terms of an *applicative functor*.

Definition A.1 (The type of a dynamic proposition)**.** The type of assignments is g; the type of (trivalent) truth-values is t; function types are constructed via $(\to)$; set types are constructed via $\{\,.\,\}$; pair types are constructed via (.). The type of a *dynamic proposition*, T, is defined as follows:

$$\mathsf{T} \coloneqq \mathsf{g} \to \{\,(\mathsf{t}, \mathsf{g})\,\}$$

Following, e.g., Chierchia 1995 we can assume that predicates denote functions from individuals to dynamic propositions:

(83) a. $[\![\text{swim}]\!] = \lambda x g\,.\,\{\,(\mathsf{swim}\ x, g)\,\}$ $\qquad \mathsf{e} \to \mathsf{T}$

b. $[\![\text{hug}]\!] = \lambda x y g\,.\,\{\,(y\ \mathsf{hug}\ x, g)\,\}$ $\qquad \mathsf{e} \to \mathsf{e} \to \mathsf{T}$

Indefinites and pronouns can both be modelled as higher-order functions that take a scope argument — indefinites introduce a set of alternatives, whereas pronouns induce potential uncertainty in the trivalent substrate. Just as in DAS, we decompose indefinites into DPL-style existential quantification and a positive closure operator.

Definition A.2 (The positive closure operator)**.**

$$\begin{aligned} \dagger\, m = \lambda g\,.\,&\{\,(\top, h) \mid (T, h) \in m\ g\,\} \\ &\cup \{\,(\bot, g) \mid \neg\exists(\top, h) \in m\ g \wedge \exists(\bot, h) \in m\ g\,\} \\ &\cup \{\,(\#, g) \mid \neg\exists(\top, h), (\bot, h) \in m\ g \wedge \exists(\#, h) \in m\ g\,\} \qquad \dagger : \mathsf{T} \to \mathsf{T} \end{aligned}$$

(84) $[\![\text{a}^n\ \text{boy}]\!] = \lambda k\,.\,\dagger\left(\lambda g\,.\,\bigcup_{\mathsf{boy}\ x} k\ x\ g^{[n\mapsto x]}\right)$ $\qquad (\mathsf{e} \to \mathsf{T}) \to \mathsf{T}$

(85) $[\![\text{he}_n]\!] = \lambda k \,.\, \lambda g \,.\, \{(\partial\,(n \in \mathsf{dom}\ g) \wedge t, h) \mid (t, h) \in k\ x\ g\}$ $\qquad (\mathsf{e} \to \mathsf{T}) \to \mathsf{T}$

Indefinites/pronouns compose with predicates (either derived or lexical), resulting in dynamic propositions. This is illustrated for an indefinite in (86), and a pronoun in (87).

(86) a. $[\![\text{a}^1\ \text{boy}]\!]\ ([\![\text{swim}]\!])$

b. $= \lambda g \,.\, \bigcup_{\mathsf{boy}\ x} (\lambda x \,.\, \lambda g \,.\, \{(\mathsf{swim}\ x, g)\})\ x\ g^{[1 \to x]}$

c. $= \lambda g \,.\, \{(\mathsf{swim}\ x, g^{[1 \to x]}) \mid \mathsf{boy}\ x\}$ $\qquad \mathsf{T}$

(87) a. $[\![\text{he}_1]\!]\ ([\![\text{swim}]\!])$

b. $= \lambda g \,.\, \{(\partial\,(n \in \mathsf{dom}\ g) \wedge t, h) \mid (t, h) \in (\lambda x \,.\, g \,.\, \{(\mathsf{swim}\ x, g)\})\ g_1\ g\}$

c. $= \lambda g \,.\, \{(\partial\,(n \in \mathsf{dom}\ g) \wedge \mathsf{swim}\ g_1, g)\}$ $\qquad \mathsf{T}$

We assume that the truth-functional operators have a strong Kleene semantics.

(88) a. $[\![\text{not}]\!] := \lambda t \,.\, \neg_s\ t$ $\qquad \mathsf{t} \to \mathsf{t}$

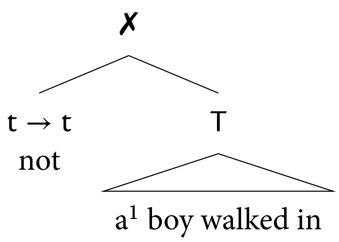
b. $[\![\text{and}]\!] := \lambda u t \,.\, t \wedge_s\ u$ $\qquad \mathsf{t} \to \mathsf{t} \to \mathsf{t}$

c. $[\![\text{or}]\!] := \lambda u t \,.\, t \vee_s\ u$ $\qquad \mathsf{t} \to \mathsf{t} \to \mathsf{t}$

d. $[\![\text{if}]\!] := \lambda t u \,.\, t \to u$ $\qquad \mathsf{t} \to \mathsf{t} \to \mathsf{t}$

As it stands, the truth-functional operators won't compose with dynamic propositions — the types don't match, as shown in (89).

(89)



In order to address this, we'll make use of the expressive power of an *applicative functor* to lift the truth-functional operators into the dynamic setting. An applicative functor is a mathematical structure used in the functional programming and computer science literature for characterizing an enriched type space and an appropriately enriched notion of function application (Mcbride & Paterson 2008). For work explicitly using applicative functors in linguistic semantics, see, e.g., Charlow 2019a,c, but it's also worth emphasizing that applicative functors are *implicit* in much of semantic theorizing. Concretely, an applicative functor consists of a type constructor F, and two accompanying operations: $\eta : \mathsf{a} \to \mathsf{F}\ \mathsf{a}$ and $\circledast : \mathsf{F}\ (\mathsf{a} \to \mathsf{b}) \to \mathsf{F}\ \mathsf{a} \to \mathsf{F}\ \mathsf{b}$. The definition of the `State.Set` applicative is given below.

Definition A.3 (The `State.Set` applicative)**.** The `State.Set` applicative consists of a type constructor S, and two operators η and $\circledast$ defined as follows:

$$
\begin{array}{ll}
\mathsf{S\,a} \coloneqq \mathsf{g} \to \{\,(\mathsf{a},\mathsf{g})\,\} & \\
\eta\; x \coloneqq \lambda g\,.\,\{\,(x,g)\,\} & \eta : \mathsf{a} \to \mathsf{S\,a} \\
m \circledast n \coloneqq \lambda g\,.\,\{\,(f\;x,i) \mid \exists h[(f,h) \in m\;g \wedge (x,i) \in n\;h]\,\} & \circledast : \mathsf{S\,(a \to b)} \to \mathsf{S\,a} \to \mathsf{S\,b}
\end{array}
$$

To qualify as an applicative functor η and $\circledast$ must obey the applicative functor laws, which ensure that the operations are "well-behaved"; η should do nothing more than trivially lift values into the space characterized by S, and $\circledast$ should characterize a notion of function application, suitably enriched for S. The laws are given below — it should be easy to check that η and $\circledast$ as defined here indeed obey the applicative laws.

Definition A.4 (The applicative laws)**.** η and $\circledast$ must obey the following laws to qualify as an applicative functor.

Homomorphism $\eta\; f \circledast \eta\; x = \eta\;(f\;x)$

Identity $\eta\;(\lambda x\,.\,x) \circledast m = m$

Interchange $\eta\;(\lambda k\,.\,k\;x) \circledast m = m \circledast \eta\; x$

Composition $\eta\;(\circ) \circledast m \circledast n \circledast o = m \circledast (n \circledast o)$

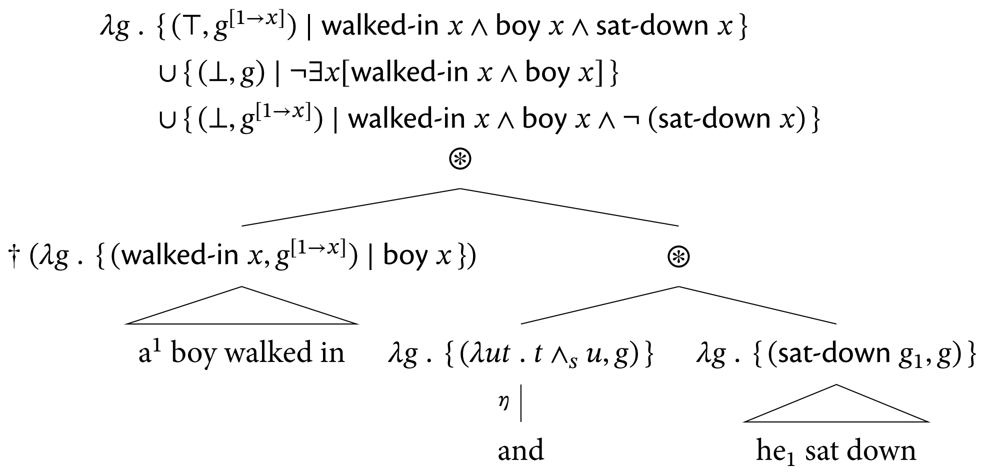
The type of a dynamic proposition (T), is simply our applicative type constructor applied to t, i.e., S t. We can now use the operations associated with the `State.Set` applicative to compose the truth-functional operators with dynamic propositions. This is illustrated in (90) for sentential negation, and (91) for conjunction; the truth-functional operator is simply lifted into the enriched type space via η, and composes with its arguments via $\circledast$.

(90)

$$
\begin{array}{c}
\lambda g\,.\,\{\,(\bot, g^{[1\to x]}) \mid \mathsf{swims}\; x \wedge \mathsf{boy}\; x\,\} \\
\cup \{\,(\top, g) \mid \neg\exists x[\mathsf{swims}\; x \wedge \mathsf{boy}\; x]\,\} \\
\circledast
\end{array}
$$

$$
\begin{array}{cc}
\lambda g\,.\,\{\,(\lambda t\,.\,\neg_s\, t, g)\,\} & \dagger\;(\lambda g\,.\,\{\,(\mathsf{swims}\; x, g^{[1\to x]}) \mid \mathsf{boy}\; x\,\}) \\
\eta \mid & \\
\text{not} & \text{a}^1 \text{ boy swims}
\end{array}
$$

(91)



State.Set has been prominently used in its *monadic* guise in Charlow's (2014, 2019b) work on dynamic semantics and exceptional scope. A *monad* (Wadler 1995) is strictly more powerful than an applicative functor, and comes furnished with an additional operation *bind*. Charlow provides a compelling argument that the full power of a monad is necessary for capturing the exceptional scope-taking capacity of indefinites, and indeed decomposes DPL-style existential quantification into bind applied to an alternative set. The applicative grammar outlined here is not straightforwardly compatible with Charlow's proposal, since our entry for indefinites is somewhat more involved. We leave the question of how to reconcile DAS with mechanisms for achieving exceptional scope to future work.

B. ∀-readings via pragmatic strengthening

In §2.9, I showed that a straightforward lifting of strong Kleene material implication into a dynamic setting systematically predicts ∃–readings of donkey sentences. To recap, we predict (92) to be (i) *true* iff either nobody is here, or someone is here and unhappy, and (ii) *false* iff nobody is here and unhappy, and someone is here and happy. The existential truth conditions are however weaker than what is typically reported in the literature — (92) is judged to be true iff *everyone* who is here is unhappy (the ∀-reading). The falsity conditions on the other hand seem intuitively correct.[30] We actually make exactly the same predictions for the bathroom disjunction in (93), which Krahmer & Muskens (1995) report has a ∀-reading, at least in a UE environment.

(92) If anyone[1] is here, then they$_1$ are unhappy.

(93) Either nobody[1] is here, or they$_1$ are unhappy.

In this section, I'll outline one possible way to derive ∀-readings. I won't argue in detail that this is in fact a totally satisfactory account of donkey anaphora (see, e.g., Champollion, Bumford

[30] Here I follow Chierchia (1995), who introduces the terms ∃-reading and ∀-reading, rather than the more commonly used *weak* and *strong* readings; as Chierchia these terms are misleading since, the logical strength of the reading depends on the monotonicity properties of the environment.

& Henderson 2019 for a detailed discussion of the empirical desiderata), but I believe it is important to show that ∀-readings can, in principle, be derived on the basis of independently motivated pragmatic strengthening mechanisms in a DAS setting. The idea will be to locate the ∃/∀ ambiguity in the landscape of a broader set of phenomena, such as homogeneous predication, which exhibit ∃-readings in Downward Entailing (DE) contexts, and ∀-readings in UE contexts. Following recent work by Bar-Lev (2018), we'll sketch an analysis in which the ∃-reading is treated as basic, and the ∀-reading is derived as an implicature.[31]

We'll motivate our analysis of ∀-readings on the basis of a parallel with homogeneity effects — consider the following examples. In a UE context, the attested reading is *universal*, whereas in a DE context, the attested reading is *existential*.[32]

(94) a. The boys played chess. *every boy played chess* (✓ ∀, ✗∃)

b. The boys didn't play chess. *no boy played chess* (✗$\neg > \forall$, ✓$\neg > \exists$)

Bar-Lev (2018) provides extensive arguments that the ∃-reading should be treated as basic, and the ∀-reading should be derived as an implicature (see also Magri 2009, 2014). The analysis is framed within the grammatical theory of implicature, in which a silent operator $\mathcal{E}x\hbar$ is responsible for implicature computation. The idea, informally, is that $\mathcal{E}x\hbar$ doesn't just negate innocently excludable (IE) alternatives, but also asserts innocently includable (II) alternatives. In order to compute the II alternatives, we first take ϕ' to be ϕ strengthened relative to the IE alternatives. We then take the maximal sets of alternatives which don't jointly contradict ϕ'; the alternatives that belong to all such sets are the II ones. In the following examples, none of the relevant alternatives will be IE, so we can focus on the latter clause (but see Bar-Lev for the full definition, and Fox 2007 on innocent exclusion).

In order to apply this mechanism to homogeneous predication, Bar-Lev suggests that (94a) has weak, existential truth-conditions — this is cashed out via an existential distributivity operator, which is (crucially) restricted by a silent domain variable D.[33]

(95) $[\![\text{the boys played chess}]\!] = 1 \text{ iff } \exists X \subseteq (D \cap [\![\text{the boys}]\!])[[\![\text{played chess}]\!]\ X]$

The distributivity operator is assumed to induce *subdomain* alternatives (Chierchia 2013), i.e., alternatives derived by replacing the domain variable with a subset. The resulting alternatives are *not* IE, but they *are* II. Asserting all such alternatives will strengthen the weak, existential truth conditions into strong, universal truth conditions, as illustrated in (96). In a DE context, on the other hand, the subdomain alternatives are logically weaker than the literal meaning of the sentence, and therefore have no effect.

(96) $[\![\mathit{Exh} \text{ the boys played chess}]\!]$

$= 1 \text{ iff } \exists X \subseteq (D \cap [\![\text{the boys}]\!])[[\![\text{played chess}]\!]\ X]$

$\wedge \bigwedge \{\exists x \subseteq (D' \cap [\![\text{the boys}]\!])[[\![\text{played chess}]\!]\ x] \mid D' \subseteq D\}$

[31] Moshe Bar-Lev and Keny Chatain independently developed an approach to universal readings like the one outlined here, but the work was never published (thanks to [redacted] p.c. for pointing this out).

[32] See also Bassi & Bar-Lev (2018) on bare conditionals, and Bar-Lev & Fox (2017) on free choice.

[33] For concreteness, I assume that pluralities are sets of individuals (Bennett 1974, Schwarzschild et al. 1996).

In order to extend this analysis to donkey sentences, we assume that indefinites come with a silent domain variable D, which induces subdomain alternatives, as in (97). Ordinary scalar alternatives derived by replacing the indefinite with, e.g., *everyone* are not considered — the result is not a felicitous sentence, since only existentials license donkey anaphora (see (98)).

(97) If [anyone^1 D] is here, then they$_1$'re unhappy. $\exists^1 (D\,1 \land H\,1) \to U\,1$

(98) #If everyone^1 is here, then they$_1$'re happy.

Assuming that there are two individuals, a and b, the truth-conditions of the subdomain alternatives to (97) will be as follows:

- Either a isn't here, or a is here and unhappy. $H\,a \to U\,a$
- Either b isn't here, or b is here and unhappy. $H\,b \to U\,b$

If we conjoin (97) with its II alternatives we get the following, strengthened meaning. This is equivalent to: *everyone who is here is unhappy*. To see this, imagine that a is here and unhappy, but b is here and unhappy. This verifies the first conjunct and the second conjunct, but the third conjunct is falsified.

(99) Either nobody is here, or someone is here and unhappy
and, either a isn't here, or a is here and unhappy.
and, either b isn't here, or b is here and unhappy.

We've successfully derived the ∀-reading, and we furthermore we successfully predict that this reading should be absent in a sentence without donkey anaphora, such as (100). This is because (100) has at least one IE scalar alternative (101), which will prevent inclusion of subdomain alternatives.

(100) Someone who is here is unhappy.

(101) Everyone who is here is unhappy.

Out of necessity we leave it to future work whether this is a realistic account of ∃/∀-readings of donkey sentences. The purpose of this section was merely to show that ∀-readings can, in principle, be derived in a non ad hoc fashion.

Word count: 14681