

The semantics of N-by-N adverbials

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Abstract. Noun-by-noun adverbials refer to constructions in English where duplicated nouns are linked by the preposition *by*. This paper provides a new compositional analysis based on contextually resolved free variables that N-by-N adverbials require a non-trivial temporal partition of the event they modify and further quantize the rate (differential-distributive) or the participants (participant-distributive) for each cell under this partition. This analysis is able to unify previous analyses of N-by-N adverbials (Beck and Stechow 2007; Henderson 2013) and capture their interactions with numbers and salient subevents.

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1. Introduction. N-by-N adverbials refer to constructions in English like those in example (1), where reduplicated nouns are linked by the preposition *by*. And we can observe that two types of reading can be derived from N-by-N adverbials:

- (1) a. The boys ate apples **one by one**. (*participant-distributive*)
 b. The performers whirled **dancer by dancer**. (*participant-distributive*)
 c. The crack widened **inch by inch**. (*differential-distributive*)

Under a *participant-distributive* reading, the N-by-N adverbial requires the event it modifies to contain a plurality of subevents and specifies the number of participants in each subevent. This is common when N-by-N adverbials contain duplicated numbers as in (1a) or sortal nouns as in (1b). On the other hand, *differential-distributive* readings also require the event to contain a plurality of subevents but instead specify the degree of change in some participants along some dimension during the course of each subevent. This is common for N-by-N adverbials with duplicated unit nouns as in (1c).

This paper will argue for a new analysis of N-by-N adverbials that they require a plural event and quantize the rate (when the N is a unit noun) or the participants (when N is a number or a sortal noun) of each subevent based on contextually interpreted free variables. It differs from previous analyses in that it does not link N-by-N adverbials to scalar change (Henderson 2013) or to the mereological make-up of some participants (Beck and Stechow 2007). And as a result, this paper is able to provide a unified analysis of N-by-N adverbials containing different types of nouns and capture their interaction with numbers and subevents. Section 2 will present this new analysis for N-by-N adverbials. Sections 3 and 4 will discuss N-by-N adverbials' interactions with numbers and subevents, respectively. Section 5 will compare this analysis to previous approaches by Henderson (2013) and Beck and Stechow (2007), followed by the conclusion in section 6.

2. The semantics of N-by-N adverbials. The lexical entry given in (2) for N-by-N adverbials requires there to be a non-trivial temporal partition of some event e where all cells in this partition $\pi_\tau(e)$ are some contextually determined atomic events $V_\alpha(e')$ and each cell can be measured in some way $N(I(e'))$ to return the number n_N that is associated with the noun in the N-by-N adverbial (which is 1 by default). Compositionally, N-by-N adverbials are of type $\langle v, t \rangle$

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just like most other event-modifying adverbs and they combine with some verbal projection that is also of type $\langle v, t \rangle$ through predicate modification.

$$(2) \quad \mathbf{N\text{-}by\text{-}N}_{\langle v, t \rangle} : \lambda e. \exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). V_{\alpha}(e') \wedge N(I(e')) = n_{\mathbf{N}}$$

π_{τ} is a non-trivial partition function (Balusu 2006) that contextually divides an event e into a set of non-overlapping cells along the temporal dimension. V_{α} imposes an atomic property requirement (Krifka 1998) on an event e , where $V_{\alpha}(e)$ is true if and only if e is an atom with the contextually determined property $V_{\langle v, t \rangle}$ and does not contain any proper parts with the property $V_{\langle v, t \rangle}$. A formal denotation of $V_{\alpha}(e)$ is given below:

$$(3) \quad V_{\alpha}(e): \text{ATOM}(e) \wedge V(e) \wedge \sim \exists e'. [e' < e \wedge V(e')]$$

The free interval function I is contextually resolved to a trace function $i_{\Delta, \Theta}(e) \langle v, i \rangle$, a path function $\sigma/\tau(e) \langle v, i \rangle$, or to a mereological count function $|\Theta(e)| \langle v, n \rangle$; and when the noun \mathbf{N} in the adverbial is a sortal noun, I imposes the additional requirement that $\mathbf{N}(\Theta(e))$. The free unit function N is contextually resolved to the identity function ID when I is set to a mereological count function, or to a unit function $\mu(i) \langle i, n \rangle$ otherwise.

This paper follows the formal framework proposed by Champollion (2017) with two deviations that go hand in hand with each other: a) unit functions can only take intervals and not degrees as their arguments, b) and degrees must be converted into intervals before applying a unit function. This makes intuitive sense since degrees cannot be straightforwardly measured as they represent points on a scale, which is in itself an ordered set of degrees. Instead, only intervals can be measured as they represent distances on a scale and degrees must be converted into intervals that represent their distance from the lower endpoint of the scale before being measured, since units are conventionally defined arbitrary intervals along some dimension. This straightforwardly explains why unit functions can take an interval and return a number, as it divides up the input interval with the interval of the unit and return the result as its output. This also has the practical advantage of simplifying unit functions such that they only take intervals as arguments since both runtime τ and spatial extent σ are intervals inherently associated with the events that can be measured by unit functions under the framework in the Champollion (2017).

Participant function $\Theta \langle v, e \rangle$ is contextually resolved to some theta role of the event e . Unit function $\mu \langle i, n \rangle$ takes an interval, divides it by a unit and returns the resulting number. Count function $|\cdot| \langle v/e, n \rangle$ takes an individual ranging from type v to type e and returns the number of atomic parts in this individual. Path function $\sigma/\tau \langle v, i \rangle$ measures the spatial extent (σ) of e or the runtime (τ) of e , which are intervals inherently associated with events. Trace function $\langle v, i \rangle i_{\Delta, \Theta}$ traces the interval between the degree of some participant along some dimension at the start of an event e and the degree of the same participant along the same dimension at the end of event e .

When the noun in the \mathbf{N} -by- \mathbf{N} adverbial is a number, I is set to a count function and applies to some participants of the subevents while N is set to the identity function ID .

(4) The boys ate apples **one by one**. (*participant-distributive*)

$$\begin{aligned} & \exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). \text{eat}_{\alpha}(e') \wedge |\text{AGENT}(e')| = 1 \\ & \exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). \text{eat}_{\alpha}(e') \wedge |\text{PATIENT}(e')| = 1 \end{aligned}$$

For example, the adverbial *one by one* contributes the meaning that there is a non-trivial temporal partition of the event it modifies where each cell is an atomic eating event and either the agent or the patient in each cell contains only one atomic part. The underspecified denotation of \mathbf{N} -by- \mathbf{N} adverbials in (2) correctly predicts that (4) is ambiguous as to whether it is describing the number of atomic agents or patients in each subevent. Section 2 will provide examples where

some readings for N-by-N adverbials are contextually ruled out by their interactions with numbers.

When the noun in the N-by-N adverbial is a sortal noun N , I is also set to a count function and applies to some participants of the subevents while N is set to the identity function ID. And an additional requirement is imposed that the participant of each subevent must also have the property of being N , *i.e.* $N(\Theta(e))$:

- (5) The performers whirled **dancer by dancer**.¹ (*participant-distributive*)
 $\exists \pi_\tau(e). \forall e' \in \pi_\tau(e). \text{whirl}_\alpha(e') \wedge |\text{AGENT}(e')| = 1 \wedge \text{dancer}(\text{AGENT}(e'))$

In sentence (5), the adverbial *dancer by dancer* contributes the meaning that there is a non-trivial temporal partition of the event it modifies where each cell is an atomic whirling event and the agent of each atomic whirling event contains only one atomic part which is a dancer.

When the noun in the N-by-N adverbial is a unit noun, I is set to a path or a trace function, and N is set to a unit function corresponding to the unit noun itself:

- (6) a. The crack widened **inch by inch**. (*differential-distributive*)
 $\exists \pi_\tau(e). \forall e' \in \pi_\tau(e). \text{widen}_\alpha(e') \wedge \text{inch}(\text{WIDTH}_{\Delta, \text{THEME}}(e')) = 1$
 b. The kangaroo hopped across the field **meter by meter**. (*differential-distributive*)
 $\exists \pi_\tau(e). \forall e' \in \pi_\tau(e). \text{hop}_\alpha(e') \wedge \text{meter}(\sigma(e')) = 1$

In sentence (6a), the adverbial *inch by inch* contributes the meaning that there is a non-trivial temporal partition of the event it modifies where each cell is an atomic *widening* event, and the change in the width of the theme between the start and the end of each subevent measures up to precisely 1 inch. And in sentence (6b), the adverbial *meter by meter* contributes the meaning that there is a non-trivial temporal partition of the event it modifies where each cell is an atomic *hopping* event and the spatial extent of each *hopping* event is precisely 1 meter.

Some sortal nouns can be used as make-shift units. They differ from more typical unit nouns in that the quantity of these make-shift units is not fixed and depends on the context in which they are used. For example, *slice* is such a noun and it can be used as a make-shift unit for volume (as in *a slice of pizza*). Interestingly, N-by-N adverbials can derive similar if not identical truth conditions when the noun is a make-shift unit in the adverbials:

- (7) a. John ate his pizza **slice by slice**. (*participant-distributive*)
 $\exists \pi_\tau(e). \forall e' \in \pi_\tau(e). \text{eat}_\alpha(e') \wedge |\text{PATIENT}(e')| = 1 \wedge \text{slice}(\text{PATIENT}(e'))$
 b. John ate his pizza **slice by slice**. (*differential-distributive*)
 $\exists \pi_\tau(e). \forall e' \in \pi_\tau(e). \text{eat}_\alpha(e') \wedge \text{slice}(\text{VOLUME}_{\Delta, \text{PATIENT}}(e')) = 1$

Under the *participant-distributive* reading in (7a), the adverbial *slice by slice* contributes the meaning that there is a non-trivial partition of the event it modifies where each cell is an atomic eating event and the patient of each cell contains only one atomic part which is a slice. And under the *differential-distributive* reading in (7b), the adverbial *slice by slice* contributes the meaning that there is a non-trivial partition of the event it modifies where each cell is an atomic eating event, and the change in volume of the patient between the start and the end of each subevent measures up to precisely 1 slice. By appealing to underspecification and contextually saliency, this interaction between N-by-N adverbials and make-shift unit nouns is expected as these nouns are ambiguous and can be interpreted as being sortal or as units.

¹ Example (5) is based on an example from Henderson (2013) which he claimed to be ungrammatical. However, this judgment is not shared by me or some of my colleagues who find (5) to be perfectly acceptable.

3. Interaction with numbers. Since the meaning of N-by-N adverbials is derived contextually, it is expected that some contexts can rule out otherwise available readings. And as it turns out, N-by-N adverbials are sensitive to the plurality of the participants in the event they modify. For example, N-by-N adverbials can only distribute over plural participants in the main event when under a *participant-distributive* reading:

- (8) a. The dogs ate apples **one by one**.
 $\exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). eat_{\alpha}(e') \wedge |AGENT(e')| = 1$
 $\exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). eat_{\alpha}(e') \wedge |PATIENT(e')| = 1$
- b. The dogs ate an apple **one by one**.
 $\exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). eat_{\alpha}(e') \wedge |AGENT(e')| = 1$
 $\# \exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). eat_{\alpha}(e') \wedge |PATIENT(e')| = 1$
- c. The dog ate apples **one by one**.
 $\# \exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). eat_{\alpha}(e') \wedge |AGENT(e')| = 1$
 $\exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). eat_{\alpha}(e') \wedge |PATIENT(e')| = 1$
- d. The dog ate an apple **one by one**.
 $\# \exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). eat_{\alpha}(e') \wedge |AGENT(e')| = 1$
 $\# \exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). eat_{\alpha}(e') \wedge |PATIENT(e')| = 1$

In sentence (8a), *one by one* can target both the agent and the patient since both are plural, which in turn makes the sentence ambiguous between these two readings. But in sentence (8b), the patient distributive reading is ruled out as the patient in the main event is singular. This makes it impossible to derive a non-trivial temporal partition of the main event where the patient in each cell is an atomic apple (as this would require there to be at least two apples to be eaten by the dogs). Similarly, the agent distributive reading is ruled out in (8c) as the agent of the main event is just one dog. And the lack of plural participants in the main event has rendered (8d) infelicitous.

The same effects can be observed when the noun in the N-by-N adverbial is *sortal*:

- (9) a. The students watched those movies **group by group**.
 $\exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). watch_{\alpha}(e') \wedge |AGENT(e')| = 1 \wedge group(AGENT(e'))$
 $\exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). watch_{\alpha}(e') \wedge |PATIENT(e')| = 1 \wedge group(PATIENT(e'))$
- b. The student watched those movies **group by group**.
 $\# \exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). watch_{\alpha}(e') \wedge |AGENT(e')| = 1 \wedge group(AGENT(e'))$
 $\exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). watch_{\alpha}(e') \wedge |PATIENT(e')| = 1 \wedge group(PATIENT(e'))$
- c. The students watched that movie **group by group**.
 $\# \exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). watch_{\alpha}(e') \wedge |AGENT(e')| = 1 \wedge group(AGENT(e'))$
 $\exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). watch_{\alpha}(e') \wedge |PATIENT(e')| = 1 \wedge group(PATIENT(e'))$

Since both the agent and the patient in sentence (9a) are plural, *group by group* means that there is a non-trivial partition of the event which it modifies where each cell is an atomic watching event and either the agent or the patient in each cell is precisely 1 atomic group. In contrast, sentences (9b) and (9c) only allow one of the two readings as both only contain one plural participant in the main event.

But N-by-N adverbials are not just sensitive to the plurality of the main event participants. When an appropriate context is chosen, they are also sensitive to the actual number of participants which is not captured by the previous analyses by Beck and Stechow (2007) and Henderson (2013):

(10) a. The dogs ate apples **pair by pair**.

$$\exists \pi_\tau(e). \forall e' \in \pi_\tau(e). eat_\alpha(e') \wedge |AGENT(e')| = 1 \wedge pair(AGENT(e'))$$

$$\exists \pi_\tau(e). \forall e' \in \pi_\tau(e). eat_\alpha(e') \wedge |PATIENT(e')| = 1 \wedge pair(PATIENT(e'))$$

b. The two dogs ate apples **pair by pair**.

$$\# \exists \pi_\tau(e). \forall e' \in \pi_\tau(e). eat_\alpha(e') \wedge |AGENT(e')| = 1 \wedge pair(AGENT(e'))$$

$$\exists \pi_\tau(e). \forall e' \in \pi_\tau(e). eat_\alpha(e') \wedge |PATIENT(e')| = 1 \wedge pair(PATIENT(e'))$$

Sentence (10a) is ambiguous and *pair by pair* can be interpreted as requiring there to be a non-trivial temporal partition of the main event where each cell is an atomic eating event and the agent or the patient in each cell is one atomic pair. But the agent distributive reading is ruled out for (10b), since it is impossible to derive a non-trivial temporal partition of the main event where the agent in each cell is a pair of dogs (as this would require there to be at least 2 pairs of dogs that ate apples). It is important to note that under this analysis, N-by-N adverbials do not impose any requirement on the plurality of the participants in the event they modify. Instead, any such checks on plurality are results from the partition process required by the N-by-N adverbials.

4. Interaction with salient subevents. Although V_α is resolved to exactly the same type of event as the main event, it can be resolved to other values when the context is appropriate. For example, the sentence in (11) cannot possibly mean that there is a non-trivial temporal partition of a *winning* event where each cell is an atomic *winning* event during the course of which the volume of either the agent or the theme has changed by precisely 1 ounce.

(11) John won the soda drinking contest **ounce by ounce**.

$$\# \exists \pi_\tau(e). \forall e' \in \pi_\tau(e). win_\alpha(e') \wedge ounce(VOLUME_{\Delta, PATIENT}(e')) = 1$$

The truth condition in (11) is false because neither the agent (John) nor the patient (the soda drinking contest) has experienced any change in volume during the event, and it is impossible to partition a *winning* event into multiple atomic *winning* subevents due to its telicity (*i.e.* this *winning* event does not contain any proper parts that are also *winning* events). Thus, V_α must be resolved to some other value other than $win_\alpha(e')$. It makes more intuitive sense to say that *won the soda drinking contest* contains multiple atomic *drinking* events instead of *winning* events:

(12) John won the soda drinking contest **ounce by ounce**.

$$\exists \pi_\tau(e). \forall e' \in \pi_\tau(e). drink_\alpha(e') \wedge ounce(VOLUME_{\Delta, PATIENT}(e')) = 1$$

In other words, *ounce by ounce* in (11) contributes the meaning that there is a non-trivial temporal partition of the event it modifies where each cell is an atomic drinking event, and the change in volume of the patient between the start and the end of each subevent measures up to precisely 1 ounce. This correctly captures the truth condition of the sentence and would not be possible unless V_α is contextually resolved, since it is impossible for the N-by-N adverbial to derive this interpretation from the adverbial it modifies purely compositionally. And as expected, a sentence would be infelicitous when N-by-N adverbials cannot identify any contextually salient subevents that can be measured along the relevant dimension:

(13) John won the Tour de France **ounce by ounce**.

$$\# \exists \pi_\tau(e). \forall e' \in \pi_\tau(e). cycle_\alpha(e') \wedge ounce(VOLUME_{\Delta, PATIENT}(e')) = 1$$

The most salient subevent in (13) seems to be a series of *cycling* events since the Tour de France is a multiple-stage bicycle race, but this option is ruled out as *cycling* events usually do not involve any change in their agent's volume and thus are unmeasurable by ounce. However, we can improve the acceptability of (13) by setting up an elaborate scenario in which John won the

Tour de France by sipping on a magic potion ounce by ounce during the race. And crucially, he would not have won the Tour de France if he did not keep to his potion drinking schedule:

(14) John won the Tour de France **ounce by ounce**.

$$\exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). \text{drink}_{\alpha}(e') \wedge \text{ounce}(\text{VOLUME}_{\Delta, \text{PATIENT}}(e')) = 1$$

Although (14) might not sound perfect, it is still a significant improvement over its context-free counterpart in (13) because the context provides a way to partition *won the Tour de France* into a series of *drinking* subevents in which the volume of the patient has reduced by 1 ounce during each *drinking* subevent. This again supports the idea that V_{α} in N-by-N adverbials is resolved contextually.

5. Comparison with previous analyses. Beck and Stechow (2007) provide a part-whole analysis for N-by-N adverbials which traces the mereological structure of some participants of an event across different subevents:

- (15) a. The performers whirled **one by one**.
 b. John ate his pizza **slice by slice**.

Under this analysis, (15a) will have the truth condition that the event modified by *one by one* is a plural event and the agent of this event is a plural individual. The parts of this event must be temporally sequenced and each atomic part of this event must contain an individual with the cardinality of 1, which in this case is given by the noun in the adverbial. And similarly, *slice by slice* in (15b) requires the event it modifies to be a plural event and the patient of this event must be a plurality of pizza slices. And all atomic parts of this event must be temporally sequenced and each of them must involve the consumption of just 1 slice of pizza.

Although the part-whole analysis can successfully capture the meaning of N-by-N adverbials when *participant-distributive* reading is involved. But as Henderson (2013) points out, this part-whole analysis fails to capture the meaning of N-by-N adverbials when there are no such mereological structures available as in (16) where the noun in the N-by-N adverbial is a unit noun (*i.e.* when *differential-distributive* reading is involved):

- (16) a. The plane descended **meter by meter**. (Henderson 2013: 484)
 b. The crack widened **inch by inch**. (Henderson 2013: 484)

Beck and Stechow (2007) would incorrectly predict that (16a) means that there is a sequence of atomic descending events and the agent of each atomic descending event is a meter-long part of the plane. They would also predict that (16b) means that there is a sequence of atomic widening events and the agent of each atomic widening event is an inch-long part of the crack.

Henderson (2013) provides an alternative analysis of N-by-N adverbials based on scalar change in order to ameliorate the aforementioned problem of a part-whole analysis. He argues that N-by-N adverbials “fix the unit the unit of scalar change and require a plural event to proceed in terms of those atomic changes” and thus these adverbials should only be able to modify verb phrases that are degree-denoting and involve scalar change such as those in (17) (Henderson 2013: 474):

- (17) a. John ate the cake **piece by piece**.
 b. **Meter by meter**, the plane slowly descended through the storm
 c. The carpenter shortened the beam **inch by inch** until it fit.

Henderson (2013) claims that N-by-N adverbials are able to modify these sentences because (17a) contains an incremental theme verb and there is a scalar dimension homomorphic to the

mereological structure of the theme, (17b) contains an inherently directed motion verb and (17c) contains a change of state verb, both of which describe how an individual changes along some scalar dimension during the course of the event.

But this scalar analysis of N-by-N adverbials suffers both theoretical and empirical drawbacks. Firstly, the theory in Henderson (2013) is not compositional and comes at the cost of divorcing NUM-by-NUM adverbials from other types of N-by-N adverbials, while it seems obvious that they all share a common semantic core. Secondly, it seems problematic to claim that a verb phrase can be inherently degree-denoting: verb phrases can only denote events or states which can be measured to return a degree or an interval by applying an appropriate measure function. In other words, ‘*The plane descended*’ only denotes that there is a *descending* event whose agent is a plane and there is no degree or scale that is inherently associated with this *descending* event unless a measure phrase is overtly inserted as in ‘*The plane descended 1000 meters*’.

Henderson (2013) supports his analysis by pointing out that incremental theme verbs should resist modification by N-by-N adverbials when they lack direct objects:

(18) *John ate slice by slice.

However, (18a) is perfectly acceptable when given an appropriate context:

(19) How did John eat his pizza? He ate slice by slice.

And this seems to be true even if we select a verb that clearly does not involve any covert objects:

(20) How does John like to read? He reads word by word.

Similarly, he claims that verbs of non-scalar change should be incompatible with N-by-N adverbials. (21a, b) contain verbs of change without order and (21c, d) contain verbs of complex change:

- (21) a. The ball floated ***foot by foot**.
b. The dancer whirled ***step by step**.
c. John exercised ***machine by machine**.
d. George shuddered ***extremity by extremity**.

However, as it turns out, these verbs do not inherently resist modification by N-by-N adverbials, as they are compatible when given appropriate contexts such as those in (22):

- (22) a. The ball floated (toward the shore) **foot by foot**.
b. The dancer whirled (to the other side of the room) **step by step**.
c. John exercised **machine by machine** (using each piece of equipment just once).
d. George shuddered **shoulder by shoulder** (trying to get the spider off him).

It seems that the issue here is whether the specific event denoted by the verb phrase matches the meaning supplied by the N-by-N adverbials. For example, *floated* only describes a manner associated with buoyancy, and whether it involves directed motion or not depends on the actual event it refers to. Hence, (21a) is only unacceptable when the ball is floating back and forth around the same spot without moving in any specific direction. In other words, (21a) is unacceptable only because the ball did not float foot by foot under the scenario conceived by Henderson (2013), and the unacceptability of (21b) and (21c) can be explained in a similar fashion. On the other hand, the issue with (21d) seems to be that the noun chosen for the N-by-N adverbials cannot be straightforwardly related to a certain partition of the *shuddering* event, just

like the Tour de France example in (13). In contrast, (22d) shows that *shuddering* can be modified with an N-by-N adverbial when a fitting noun is chosen.

Henderson (2013) also predicts that manner verbs should only be compatible with N-by-N adverbials when they are modified by a resultative as in (23b, d); and motion verbs should only be compatible with N-by-N adverbials when they are directed as in (23e), as those are the conditions under which those manner and motion verbs can be associated with scalar change:

- (23) a. *Crumb by crumb, Bill licked the plate.
 b. Crumb by crumb, Bill licked the plate clean.
 c. Lily pried the door *inch by inch.
 d. Lily pried the door open inch by inch.
 e. John climbed the ladder rung by rung.
 f. John climbed the monkey bars *rung by rung.

However, (24) shows manner verbs can be modified by N-by-N adverbials without a resultative and (23a) is only ruled out by the lack of context:

- (24) Crumb by crumb, Bill licked the (dirty) plate.

Sentence (25) shows that the issue with (23c) is that the sentence modified by *inch by inch* is itself unacceptable without a resultative modifier *open*:

- (25) *Lily pried the door.

And there does not seem to be a strong contrast in grammaticality between (23e) and (23f) because neither *climbed the ladder* nor *climbed the monkey bars* is inherently directed, similar to the situation in (21a), where N-by-N adverbials are only ruled out when the verb phrase refers to a particular event that is not compatible with the partition requirement of these adverbials.

The last point of objection against the scalar analysis of N-by-N adverbials comes from the fact that it incorrectly predicts that change of state verbs should only be compatible with units within their domains:

- (26) a. The crack widened *pound by pound.
 b. The plane ascended *ounce by ounce.

According to Henderson (2013), (26a) and (26b) are unacceptable because *widening* and *ascending* are inherently associated with the domain of width and altitude. And this renders them incompatible with N-by-N adverbials that contain weight or volume units. But (27) shows that these verbs are in fact compatible with units of weight or volume, when given appropriate contexts:

- (27) a. The weight difference between these two objects increased. It widened pound by pound.
 $\exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). \text{increase}_{\alpha}(e') \wedge \text{pound}(\text{WEIGHT}_{\Delta, \text{ID:THEME}}(e')) = 1$
 b. John won a soda drinking contest. He ascended ounce by ounce.
 $\exists \pi_{\tau}(e). \forall e' \in \pi_{\tau}(e). \text{drink}_{\alpha}(e') \wedge \text{ounce}(\text{VOLUME}_{\Delta, \text{PATIENT}}(e')) = 1$

This is expected if we dissociated change of state verbs from any particular dimension. In other words, *widening* events only require there to be an increase in the difference between two degrees along some dimension that is conventionally conceived as being horizontal, while *ascending* events work the same way but the difference increase takes place along some dimension that is conventionally conceived as being vertical. In (27a), *pound by pound* adds the

meaning that there is a non-trivial temporal partition of the event it modifies where each cell is an atomic *increasing* event during the course of which the weight difference has increased by 1 pound.² Similarly, in (27b), *ounce by ounce* requires there to be a non-trivial temporal partition of the event it modifies where each cell is an atomic *drinking* event during the course of which an ounce of soda is drunk. This would not be possible if the meaning of N-by-N adverbials (and specifically V_α) is not contextually resolved.

6. Conclusion. To sum up, this paper provides a new compositional analysis of N-by-N adverbials that they require a non-trivial temporal partition of the event they modify and further quantize the rate (*differential-distributive*) or the participants (*participant-distributive*) for each cell under this partition. And it has the advantage over previous analyses (Beck and Stechow 2007 and Henderson 2013) in that it unifies *differential-distributive* and *participant-distributive* readings by appealing to contextually resolved functions and offers empirical coverage for different types of N-by-N adverbials (including NUM-by-NUM adverbials). This analysis also correctly predicts that N-by-N adverbials are compatible with all verbs as long as appropriate contexts are provided and these adverbials are not inherently associated with a certain class of verbs or scalar change. It is further supported by interactions between N-by-N adverbials with both numbers and salient subevents, where some readings are ruled out contextually based on the partition requirement.

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² This only works if we assume that the trace function is able to detect the theme of the *increasing* event is in fact in itself a degree and simply applies the identity function to measure the interval between the weight difference at the start and the end of the *increasing* event.