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FROM SENTENCE STRUCTURE TO INTONATION CONTOUR

AN ALGORITHM FOR COMPUTING PITCH CONTOURS ON THE BASIS OF SENTENCE ACCENTS AND SYNTACTIC STRUCTURE

One of the things people cannot help doing while speaking aloud is putting their linguistic utterances into an intonational envelope. Ever since the early day of science fiction this has been viewed as a characteristic feature of human speakers which distinguishes them from speaking computers. Besides a lot of beeps and buzzes, robots typically produce monotonous speech, and they are believed to be incapable of anything better than that. This popular stereotype has been overthrown, by recent developments in speech and language technology. Now, it is possible to supplement the acoustic specification of words and sentences with prosodic information, resulting in considerable improvement of the naturalness and intelligibility of synthetic speech.

In this paper we describe and explain an algorithm for the computation of pitch contours for linguistic utterances whose syntactic shape and sentence accents are given [1]. The algorithm consists of two parts. First, it determines what syntactic information in the surface structure is (potentially) relevant for intonation. In the second step, an appropriate contour is computed. Output contours are represented in the notation developed by 't Hart and Collier (1975) for their "intonation grammar" of Dutch. In its present form the algorithm generates basic intonation patterns for Dutch utterances as spoken by someone who has carefully prepared his text. The proposed system is couched in the framework of Kempen and Hoenkamp's (1984) Incremental Procedural Grammar (IPG), a theory about the way speakers convert conceptual content into sentence form during speaking. Although the exact form of the intonation

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[1] The terms <u>intonation contour</u> and <u>pitch contour</u> will be used interchangeably throughout this paper.

algorithm as described in this paper is language specific, we believe that the computational architecture it embodies is shared by many languages.

When designing the algorithm we have attempted to take into account linguistic, psychological as well as phonetic evidence concerning a main feature of prosody: the pitch contour. In contrast with most existing (computational) models of intonation (Mattingly, 1966; Witten, 1977; Pierrehumbert, 1981; Gårding, 1983), we have paid special attention to "higher" processing stages, i.e. to the conceptual and syntactic rather than to the phonetic determinants of intonation contours. Our proposal amplifies recent psycholinguistic models of language production (Garrett, 1980; Bock, 1982; Hoenkamp, 1983; Kempen & Hoenkamp, 1984) which have left largely untouched the production of prosody. We have attempted to take into account such performance phenomena as varying speech rates, incremental sentence production, and contours spanning several sentences. In this respect, our model supplements existing linguistic analyses (Bierwisch, 1966; Nespor & Vogel, 1982). Although we subscribe to the "autonomy of intonation" hypothesis, we do not believe in a prosodic component which is largely independent from the other sentence production modules and communicates with them only at a very late stage (Collier, 1972; Cutler & Isard, 1980). Instead, we assume that all sentence production modules contribute to the prosodic form of utterances.

The first part of this Chapter is concerned with computational aspects. It contains a detailed description of the algorithm [2],

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[2] The algorithm has been implemented in the form of a program written in Franz LISP, which is running on a VAX11/780-computer under the VMS operating system. Copies of the program are available upon request. The program is part of an integrated language and speech generation system which converts meaning representations into written and spoken Dutch sentences.

preceded by a short overview of Dutch intonation and a discussion of prosody as an integrated component of the language production process. The second part discusses the linguistic and psychological background of the computational model ("design principles") and evaluates the model's behavior in the light of empirical evidence.

1. COMPUTATIONAL ASPECTS

1.1 'T HART AND COLLIER'S INTONATION GRAMMAR FOR DUTCH UTTERANCES

Intonation, or perceived speech melody, is primarily related to the course of the fundamental frequency (Fo-course) in the acoustic signal. 't Hart & Collier (1975) distinguished between three representational levels which correspond to different degrees of abstraction from the speech signal:

1) Natural course of Fo. The measurable curve of the continuous fundamental frequency in the acoustic signal.
2) Pitch contour. The audible, stylized equivalent of the natural course of the fundamental frequency, containing only the perceptually (communicatively) relevant and invariant discrete pitch movements.
3) Basic intonation pattern. An abstract, mental category of intonation, underlying an actual pitch contour and integrated in the speaker-listener's linguistic competence. It is a pure "form", completely void of tangible, material aspects, and it adds certain communicative properties to an utterance.

During the last two decades, the second level, the pitch contour, has been extensively studied for Dutch intonation (Cohen & 't Hart, 1967; Collier, 1972; 't Hart & Cohen, 1973; 't Hart & Collier, 1975; de Rooy, 1979; Willems, 1982). Among the assumptions which have guided this work, are the following. First, the tune of a sentence is not a phonological primitive in itself but is made up of a sequence of simpler elements. Second, only perceptually relevant pitch movements have to be accounted for. Contours of real speech can be replaced by simpler, stylized approximations without changing the melodic impression. Third, the physical properties of these standardized movements (such as place of onset, slope and duration) can be clearly defined. And fourth, these discrete, perceptually relevant pitch movements are produced by "voluntary" instructions to the articulatory system. All other, minor fluctuations (the "micro-intonation") are added during articulation and are not under the speaker's conscious control. If they are left out, the overall subjective impression on the listener remains the same.

On this methodological basis, an inventory was made of rather steep, simple standardized pitch-movements which occur in the fundamental frequency continuum of Dutch sentences. For both falls and rises, five types of pitch movements between the upper and lower boundary of the declination line are distinguished. (The declination line refers to the slowly downward drifting pitch-level of the utterance. Declination largely depends upon a decreasing subglottal air pressure). Descriptions of the pitch movements are presented in Table I [3].

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[3] 't Hart and Collier's grammar of Dutch intonation distinguishes between only two levels of pitch accent: presence or absence. The exact excursion height of a pitch movement is decided upon in the Articulatory Stage (see Section 1.2).

Table I. An inventory of perceptually relevant pitch movements in Dutch (after 't Hart & Collier, 1975).

Symbol	Denotation
1	The prominence-lending rise. Occurs early and abruptly in the syllable carrying word accent.
2	The continuation rise. Does not lend prominence. Occurs as late as possible in the last syllable of the word preceding a (major) syntactic boundary, and is always followed by an inaudible fall during the pause on the boundary.
3	The retarded prominence-lending rise.
4	The gradual pitch rise or inclination which extends over several adjacent syllables.
5	The extra (precursive) rise. An "overshoot" in front of a final fall A after a stretch of high declination.
A	The prominence-lending final fall which is placed on the last prominent word of a clause, and occurs abruptly but rather late in the syllable carrying word accent.
B	The postponed (non-final) fall. It does not lend prominence. Is executed in an inconspicuous way during a pause at a syntactic boundary or, directly after a rise 1, very early in the following syllable.
C	The relaxation fall.
D	The gradual fall, covering several adjacent syllables.
E	The half-fall.
0	The low level of the declination line (after a fall or before a rise).
Ø	The high level of the declination line (after a rise and before a fall).

Certain successions of these atomistic ingredients into which Fo-curves can be decomposed, build recurrent clusters; the so-called intonational blocks. There are three types: P-blocks, C-blocks and E-blocks. P stands for Prefix, C for Continuation and E for End. The intonation grammar specifies the internal structure of blocs, together with the various ways in which blocks can combine. (Optional elements are within round brackets: (). They may or may not occur. Optional elements which may occur in any number, are within square brackets: []).

The first part of 't Hart and Collier's grammar is a rule governing the position of blocks in the contour of a sentence. Blocks can be concatenated according to the following rule:

contour = [[P] C][P] E

The second part of the grammar specifies the internal structure of the blocks. Table II shows a reduced version of the original set. Only blocks containing combinations of the moves 1, 2, A and B, and starting with 0, the low level of the declination line, are shown [4].

Table II. A simplified version of 't Hart & Collier's intonation grammar

P-blocks	C-blocks	E-blocks
P1 = [0] 1 [Ø] B	C1 = [0] 1 [Ø] A [0] 2	E1 = [0] 1 [Ø] A [0] (2)
	C3 = [0] 1 [Ø] (2) B	E3 = [0] 1 [Ø] (2)
	C4 = [0] 2	E4 = [0] 2

The third part of the grammar contains certain restrictions on the combinatorial possibilities given in the first part. E.g., C4 cannot be preceded by P1.

An extensive example is given in (1). Syllables of words carrying sentence stress are underlined. The picture of the intonation contour does not represent declination. The symbols under the contour line specify intonational blocks and their pitch movements. (Notice that for a fall B within a syllable a continuous line is drawn. A fall B on a constituent boundary is indicated by a gap.)

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[4] There are two reasons for leaving the other pitch falls and rises (viz. 3, 4, 5, C, D and E) out of consideration. First, there is no clear motive for their appearance in the contour. Second, their occurrence is restricted to one accent position: sentence final. The exclusion of these pitch movements only reduces the variability of the speech signal, and never leads to contours that sound unacceptable ('t Hart & Collier, 1975: 240). A speaker who only uses the so-called "hat pattern" and other contours derived from it, will not deviate much from the intonational expections of the average Dutch listener (Collier & 't Hart, 1978: 57).

(1) De oude man zag gisteren deze vrouw, zijn vroegere secretaresse,

P1: 0 1ØB P1: 1 B C3: 0 1 Ø B C3: 0 0 1 Ø B
the old man saw yesterday this woman, his former secretary,

een mantel kopen, omdat zij een nieuwe baan met goede vooruitzichten had

C1: 1 A 0 2 P1: 0 0 1 B E1: 1 Ø A 0
buy a coat, because she had a new job with good prospects

As an introduction to the psychological and linguistic underpinnings of the model, we first sketch the place of intonation computation within the more general framework of human sentence production (Section 1.2; this discussion will be resumed in the second part of the paper). Section 1.3 is devoted to the algorithm.

1.2 The place of intonation within language production

Our theoretical account of intonation deviates most from existing analyses in that it departs from a psycholinguistic rather than a linguistic point of view. Several authors (Garrett, 1980; Bock, 1982; Kempen & Hoenkamp, 1984) have proposed to decompose the computational process of human sentence production into four stages or modules, named Conceptual, Lexico-Syntactic, Morpho-Phonological and Articulatory respectively (terms coined by Kempen and Hoenkamp, 1984).

During the first, Conceptual Stage a semantic representation is formed specifying the message the speaker intends to convey to his audience. This representation, we assume, is language independent to a large extent. In the second, Lexico-Syntactic Stage functional linguistic structures are built in the form of surface syntactic trees. The terminal nodes of such trees are abstract, pre-phonological lexical items, called "lemmas" (Kempen & Huijbers, 1983). A lemma does not contain any sound information. In the third, Morpho-Phonological Stage the phonological form ("lexeme") is retrieved for each lemma and morphological adjustments are made (inflections). Finally, the fourth, Articulatory Stage transforms the phonological code into muscular motor instructions.

Basic to our approach is the assumption that prosodic processing is not confined to a unitary phonological component which is part of the Articulatory Stage. Within each of the four modules, decisions are made which eventually determine the course of the fundamental frequency of the speech signal. This pitch contour is the result of authentic prosodic rules and cannot be fully determined on the basis of the syntactic and lexical structure of the utterance.

1. Conceptual Stage. When a conceptual representation is built up, it is supplied with tags for saliency and mode. This is done on the basis of pragmatic considerations, such as meaning contrasts with earlier utterances (saliency), and communicative intention (interrogative, declarative, imperative mode). Conceptual structures containing such tags, are handed over to the syntactic formulating mechanisms of the second Stage.

2. Lexico-Syntactic Stage. Sentence accents are assigned to lemmas on the basis of saliency tags. Though we judge it premature to give detailed rules on this topic, a proposal leading to an acceptable solution in many cases could be the following: mark as accented the head of the constituent which expresses a salient part of the conceptual representation. For example, if the meaning underlying "the old man" in sentence (1), has been tagged for saliency, then the lemma for man will receive sentence stress. The accented word will often be the last (content) word of the constituent.

Mode tags are interpreted as instructions to select a declarative, interrogative or imperative sentence form. "Mode marks" are placed before the sentence (e.g.,a "?" before an interrogative). If no such tag is specified, declarative is chosen by default.

3. Morpho-Phonological Stage. For each lemma in the surface syntactic structure the corresponding phonological form (lexeme) is retrieved. Information on number of syllables and place of word accent is thus made available. The lemmas are processed in left-to-right-order. Simultaneously with the lookup of lexemes, a pitch contour is computed which spans the whole utterance under construction. To this purpose, the surface syntactic structure is inspected (look-ahead). Instructions for pitch falls and rises are associated a) with syllables carrying word accent for those words which receive sentence stress, b) with the last syllable of words preceding prosodically marked syntactic boundaries.

4. Articulatory Stage. The discrete units of the linguistic structure (phoneme sequences) are transformed into a semi-continuous flow of speech. Such transformations belong to the so-called "micro-intonation". Factors such as sex, age and voice quality exert their influence here. Although the natural course of Fo is basically derived from the intonation contour, it depends upon specific articulatory mechanisms as well. A typical example is declination: the baseline for all pitch movements. Other examples of such adjustments are: stress-retraction which serves to eliminate clashes between accents, as in thirtéen mén --> thírteen mén (Nespor & Vogel, 1982), and the influence of consonants on the intrinsic Fo-level of following vowels (Cohen & 't Hart, 1967).

The contribution to intonation of each of the four processing stages, is summarized in Table III.

Table III. The contribution of the four sentence processing stages to intonation.

Conceptual Stage	: tags (parts of) conceptual representations for saliency and mode (speech act: command, question, statement, etc.)
Lexico-Syntactic Stage	: computes sentence accents, and adds mode marks to sentences
Morpho-Phonological Stage	: computes a pitch contour, i.e., adds to each syllable of a word instructions for pitch movements
Articulatory Stage	: transforms the assigned pitch movements into muscular motor commands (including micro-intonation)

1.3 The Algorithm

Intonation contours are computed in two steps. A Basic Intonation Pattern or BIP is determined first (Section 1.3.1); then, instructions for pitch movements are added to each lexeme (Section 1.3.2). The algorithm is capable of specifying BIPs for surface syntactic trees which are generated by Kempen and Hoenkamp's (1984) Incremental Procedural Grammar (IPG). In IPG-trees, functional and categorial nodes alternate. S, NP, N, V and Art are examples of categorial nodes. Vfin, Subj, Obj and NPhead belong to the set of functional nodes [5]. The surface syntactic structure of sentence (1) is presented in (2).

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[5] The following abbreviations are used. Categorial procedures: s (clause), np (noun phrase), ap (adjectival or adverbial phrase), pp (prepositional phrase, a (adjective of adverb), n (noun), p (preposition), v (main verb), art (article), dem-pro (demonstrative pronoun), poss-pro (possessive pronoun), pers-pro (personal pronoun), and conj (subordinating conjunction). Notice that there is no VP (Verb Phrase). Functional procedures; subj: (subject), obj: (object), smod: (sentence modifier), vfin: (finite verb), vinfin: (infinitive verb), comp: (complementizer), nmod: (noun phrase modifier), nphead: (head of noun phrase), det: (determiner), aphead: (head of adjectival or adverbial phrase), pphead: (head of prepositional phrase), and pobj: (prepositional object).

```
(2) (s (subj:
      (np (det: (art de))
          (nmod: (ap (aphead: (a oude))))
          (nphead: (n *man))))
     (vfin: (v zag))
     (smod: (ap (aphead: (a *gisteren))))
     (obj:
      (np (det: (dem-pro deze))
          (nphead: (n *vrouw))
          (nmod:
           (np (det: (poss-pro zijn))
               (nmod: (ap (aphead: (a vroegere))))
               (nphead: (n *secretaresse))))))
     (obj:
      (np (det: (art een))
          (nphead: (n *mantel))))
     (vinfin: (v kopen))
     (smod: (s (comp: (conj omdat))
               (subj: (np (nphead: (pers-pro zij))))
               (obj:
                (np (det: (art een))
                    (nmod: (ap (aphead: (a nieuwe))))
                    (nphead: (n *baan))
                    (nmod:
                     (pp (pphead: (p met))
                         (pobj:
                          (np (nmod: (ap (aphead: (a *goede))))
                              (nphead: (n *vooruitzichten)))))))))
               (vfin: (v had)))))
     #)
```

Sentence (1) contains seven so-called major constituents: functional nodes which are immediately dominated by an S. In (3) we give the major constituents of the main clause of (1).

```
(3) Subj    :  de oude man
    VFin    :  zag
    SMod    :  gisteren
    Obj     :  deze vrouw zijn vroegere secretaresse
    Obj     :  een mantel
    Vinfin  :  kopen
    SMod    :  omdat zij een nieuwe baan met goede vooruitzichten had
```

1.3.1. A notation for Basic Intonation Patterns

BIPs are defined in terms of five auxiliary symbols inserted into a sentence; ?, *, #, / and // (See Table IV). The first three of these are already present in surface structures delivered by the Lexico-Syntactic Stage. The last two symbols are inserted during Morpho-Phonological processing by rules to be specified now.

"?" is the mode marker preceding an interrogative sentence. "*" is the saliency marker which is prefixed to lemmas receiving sentence accent. "#" is an end-of-message symbol appended to a surface syntactic structure; it prevents a prosodic linking of the current sentence to the following one. "/" and "//" are attached to syntactic constituents under special circumstances. Both "/", "//" and "#" may be viewed as boundary symbols. From a linguistic point of view, "/" may be called optional, whereas "//" and "#" are obligatory.

Table IV. Auxiliary symbols used for specifying Basic Intonation Patterns.

Symbol	Denotation
/	optional prosodic boundary
//	obligatory prosodic boundary
#	end of message
*	saliency marker of a lemma
?	interrogative mode

The insertion of the BIP symbols "/" and "//" proceeds as follows. First, the "//" symbol is appended to the end of the sentence. Then one after another, all major constituents of the main S are examined for asterisked lemmas, i.e., lemmas marked for saliency. If a major constituent contains at least one asterisked lemma, two actions are performed:

A Insert "//" on both sides of the major constituent in case that constituent is of type S; in all other cases, put a "/" on the right-hand side only.

```
(4) ¦------------S-------------¦  ¦-----NP------¦ ¦-VP-¦ ¦-----PP-----¦
   (because they felt *excited) (*all visitors) (went) (to the *hall) #
  // because they felt *excited // *all visitors / went  to the *hall / # //
```

B If the major constituent contains more than one asterisked lemma, mark each NP and each S functioning as a Mod(ifier) with "//" on both sides.

```
(5) ¦-------------NP---------------¦  ¦----VP----¦ ¦----NP----¦
                   ¦------NP-----¦
   (our *manager   (mister *James))   (will marry) (my *sister) #
    our *manager // mister *James // / will marry   my *sister / # //

(6) ¦-----------------S--------------- ¦    ¦---NP----¦ ¦------VP------¦
                        ¦-------S----¦
    (because *he left   (when *I came))    (the *host) (felt *insulted) #
  // because *he left // when *I came // // the *host / felt *insulted / # //
```

The boundary symbols have a priority order which runs from "/" (lowest priority), via "//" to "#" (highest priority). When several of these symbols occur next to each other, all but one are deleted: only one exemplar of the symbol of highest priority is retained. E.g., // // -> // and / # // -> #. Boundary symbols which are not preceded by lexical material are removed as well. So (4), (5) and (6) are rewritten as resp. (7), (8) and (9).

(7) because they felt *excited // *all visitors / went to the *hall #
(8) our *manager // mister *James // will marry my *sister #
(9) because *he left // when *I arrived // the *host / felt *insulted #

Of the seven major constituents in (3), five are marked (all except the second and sixth constituent). Only the fourth constituent is in need of further internal inspection. The result of applying rules A and B to (3) is listed in (10).

(10) de oude *man / zag *gisteren / deze *vrouw // zijn vroegere *secretaresse // / een *mantel / kopen // omdat zij een nieuwe *baan met *goede *vooruitzichten had // # //

After cleaning up, the BIP of (11) is the end result.

(11) de oude *man / zag *gisteren / deze *vrouw // zijn vroegere *secretaresse // een *mantel / kopen // omdat zij een nieuwe *baan met *goede *vooruitzichten had #

1.3.2. Computing intonation contours

The algorithm uses the following devices:

-- five main functions: CONTOUR-COMP, PITCH-CHANGE, PITCH-CONT, PITCH-HIGH and PITCH-LOW;

-- five auxiliary variables: <current-symbol>, <next-symbol>, <pitch>, <mode>, and <distance>; and

-- four auxiliary functions: BOUNDARY?, CHOOSE, END? and LOOK-AHEAD.

The main functions (see Table V) consist of condition-action pairs. The conditions pertain to current values of variables, or values computed by auxiliary functions. (The symbol "&" in Table V indicates boolean conjunction; the symbol ";" is a separator between successive actions). The actions consist of calling other functions, assigning values to variables, or attaching pitch movement symbols to the current symbol (e.g., action "A" is to be read as an abbreviation for "attach A to <current-symbol>"; <current-symbol> points to a word of the sentence). The auxiliary functions are somewhat more diverse. We have described their operations in Table VI.

The algorithm starts with setting <pitch> to 0, <mode> to DEC (= declarative), <distance> to 0, <current-symbol> to the first symbol in the BIP, and <next-symbol> to the second symbol in the BIP. A BIP symbol is a word of the sentence or an auxiliary symbol form the set ? / // #. The top-level function is CONTOUR-COMP. It is called once for each BIP symbol. (The three boundary symbols are skipped, however. They do not cause a call to CONTOUR-COMP; only <distance> is set to 0.) CONTOUR-COMP traverses the BIP from left to right. The actions of the PITCH-functions consist of calling an auxiliary function and/or attaching one or more pitch movement symbols from the set 1 2 A B 0 Ø to <current-symbol>. Pitch movements 1 and A are attached to the syllable carrying word accent; 2 and B to the final syllable of the word. If an A or B is chosen this implies setting <pitch> to 0; a 1 sets <pitch> to Ø and 2 leaves the value of <pitch> unaffected. In Appendix A we give a partial trace of how the algorithm processes the first seven words of sentence (1).

Table V. The main functions of the algorithm

Function Name: CONTOUR-COMP

CONDITION	ACTION
<current-symbol> is	
?	set <mode> to INT
*word	PITCH-CHANGE
<pitch> = Ø	PITCH-HIGH
<pitch> = 0	PITCH-LOW

Function Name: PITCH-CHANGE

CONDITION	ACTION
<pitch> = 0	1; PITCH-CONT
<pitch> = Ø	A; BOUNDARY?

Function Name: PITCH-CONT

CONDITION	ACTION
LOOK-AHEAD = False	B
LOOK-AHEAD = 0 &	
<mode> = INT & END? = True	CHOOSE (Ø,A); BOUNDARY?
END? = False	CHOOSE (Ø,A); BOUNDARY?
in all other cases	A
in all other cases	CHOOSE (Ø,B); BOUNDARY?

Function Name: PITCH-HIGH

CONDITION	ACTION
<next-symbol> = # & <mode> = INT	CHOOSE (2,Ø)
<next-symbol> = //	B
<next-symbol> = / &	
LOOK-AHEAD = 0	0
LOOK-AHEAD = 1	CHOOSE (Ø,B)
LOOK-AHEAD > 1	B
in all other cases	Ø

Function Name: PITCH-LOW

CONDITION	ACTION
<next-symbol> = # & <mode> = INT	CHOOSE (2,0)
<next-symbol> = //	2
<next-symbol> = / & LOOK-AHEAD > 0	CHOOSE (0,2)
in all other cases	0

Table VI. The auxiliary functions of the algorithm

BOUNDARY?	looks whether <next-symbol> is a member of the set / // #, i.e., <distance> equals 0. If so, PITCH-HIGH is executed when <pitch> = Ø or PITCH-LOW when <pitch> = 0. In all other cases, <distance> is set to the number of words before the first occurrence of a member of the set / // #.
CHOOSE(X,Y)	makes a choice between X and Y. Both alternatives will lead to an acceptable contour. [A choice may be influenced, among other things, by speech tempo, emotion, or stylistics. In some cases the value of <distance> is important. The first argument, X, is normally preferred to the second, Y. Since concrete, programmable rules are missing, we had to take recourse to a probabilistic function selecting between X and Y.]
END?	looks forward to the first occurrence of either // or #. If # is encountered, the function returns True. In all other cases False is returned.
LOOK-AHEAD	computes two scores: sc1: the number of *words (sentence accents) inbetween <current-symbol> and the first occurrence of /, // or # sc2: the number of *words inbetween <current-symbol> and the first occurrence of // or #. The function returns one of the following values: False — if sc1 > 1 False — if sc1 = 1 and sc2 > 1 sc2 — in all other cases.

2. LINGUISTIC AND PSYCHOLOGICAL ASPECTS

2.1 Design principles of intonation contour computation

Models of intonation that have been proposed in the literature tend to be confined to processing in the Articulatory Stage and to leave the higher sentence production processes out of consideration (de Pijper, 1983). Our model of Dutch intonation is an attempt at modelling intonational processing during the Morpho-Phonological Stage. The following three principles, derived from empirical (psycho)linguistic studies, have guided our work.

A. Intonation contours are computed in two stages.

1. The Lexico-Syntactic Stage assigns sentence accents to lemmas which serve specific syntactic functions, as part of the computation of surface syntactic trees.
2. The Morpho-Phonological Stage assigns instructions for pitch movements to syllables as part of the computation of word shapes.

B. Computation of intonation contours proceeds left-to-right with limited look-ahead (not beyond the current finite clause).

C. Computation of intonation contours is accent-driven (vs. syntax-driven).

The computation of an intonation contour requires knowledge about the number of accented words before the next finite clause boundary (see auxiliary function LOOK-AHEAD, Table VI). This implies that contours can only be computed after accents have been assigned. The analysis of speech errors suggests that accents are assigned to lemmas which fulfil a specific syntactic function. This takes place during the Lexico-Syntactic Stage (Fromkin, 1973; Garrett, 1980). For example word exchange errors (e.g. (12)) leave the position of sentence accents untouched. This stage, however, is an unlikely candidate for contour computation because word accent and syllable stucture are not yet available. A more favorable place would be the Morpho-Phonological Stage. It is an economical solution to have contour computation proceed along with other phonological processing for syllable structure and word accent. Along with the lookup of each lexeme, instructions for conspicuous pitch movements can be added to the syllables [6]. [The Articulatory Stage can be left out of consideration because it appears to work roughly phrase by phrase (cf. Bock, 1982), whereas contour computation needs look-ahead of the size of finite clauses.]

(12) We have a làboratory in our computer

A two-stage processing scheme does not imply an exclusively syntactic or semantic account of the origin of pitch accents. A semantic base for sentence accents is suggested by such diverse sources of evidence as connected speech (Nooteboom & Terken, 1982), (early) child language (Wieman, 1976; Pechmann, 1983) and speech repairs (Levelt & Cutler, 1983). Syntax-based rules for assigning sentential stress have been proposed mainly within the frameword of Transformational Generative Grammar (see e.g. Bresnan, 1971). Although they have lost much of their initial attraction, they cannot be completely discarded (Cutler & Isard, 1980; Nooteboom & Terken, 1982). So, a model of intonation must, in principle, be capable to incorporate more than one base for stress assignment. Our model satisfies this requirement.

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[6] This is in contrast with Fromkin's (1973) suggestion to place contour computation in a separate component preceding lexeme lookup. Cutler and Isard (1980) argue that lexical lookup precedes accent placement. However, they fail to distinguish between lemma versus lexeme lookup. Lexemes may still be retrieved after accent assignment.

If the final form of intonation contours is computed left-to-right during the Morpho-Phonological Stage (design principle B), it follows that only the surface structure of the utterance is of relevance. Even within the context of transformational grammar this has been accepted (Bierwisch, 1966; Pierrehumbert, 1981). That deep structure could play a role is denied, among other things, by disambiguation phenomena. A deep structure ambiguity can be prosodically marked only if a surface structure difference exists (Wales & Toner, 1980). Cooper and his associates, houwever, maintain that a single level of syntactic coding is not sufficient: the syntactic representation a speaker needs for intonational processing includes both underlying and surface levels of coding (Sorensen & Cooper, 1980). However, as they admit themselves (Cooper & Sorensen, 1977; Cooper, 1980), their experimental results do not necessitate an explanation in terms of a direct access of the phonetic component to deep structure information [7].

The third design principle holds that contour computation is accent- rather than syntax-driven. By this we mean that syntactic constituents are irrelevant to the shape of the intonation contour as long as they do not contain a sentence accent. This principle contrasts with the linguistic approach which seeks a more direct correspondence between "phonological phrases" and syntactic constituents, for instance, on the basis of depth of syntactic boundaries, the number of structural brackets, the number of nodes separating two successive words, and the like. That this solution is infelicitous, can be shown even with such a

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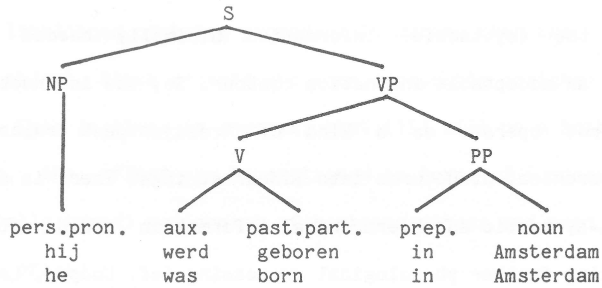
[7] Our implementation shows that "superficial" inspection of syntactic structure in combination with knowledge about the places of pitch accents can explain the results of Cooper's experiments on preposing and gapping without any reference to a "double syntactic coding". Though, in his experiments, he monitors Subjects' responses for contrastive or emphatic stress, Cooper can not prevent his speakers form producing any pitch accents at all.

simple and short sentence as (13). We owe the example to de Rooy (1979).

(13)



If we take number of non-terminal nodes between words as an index of boundary depth, the following scores are assigned to (13):

hij/4 werd/1 geboren/3 in/1 Amsterdam.

Assuming that the deepest syntactic boundary is the prime candidate for prosodic realization, one predicts a phonetic boundary after <u>hij</u>. However, "speakers realizing such a boundary at that position also realize a pitch accent on the pronoun. This accent appears to suggest some sort of contrast. If the pronoun is not realized with a pitch accent a boundary realized after the pronoun clearly suggests hesitation on the part of the speaker. Hence the realization of a normal prosodic boundary in this position involves the realization of a pitch accent on the pronoun" (de Rooy, 1979: 122). So, the syntax-driven approach can lead to putting sentence accents at places where the speaker does not need them.

We wish to conclude this Section with a remark on the general design of our algorithm. We do not claim psychological plausibility for splitting the algorithm into two successive parts: BIP coding, and contour computation. This was done to make the structure of the model more transparent and easier to describe. In reality, inspection of surface structure and computation of a contour proceed concurrently. The

BIP coding rules given in Section 1.3.1 are actually carried out by the auxiliary functions which look ahead into the sentence surface structure. They uncover the (syntactic) information minimally needed for the computation of an acceptable intonation contour. So, the instructions for BIP coding do not operate as a kind of "readjustment rules" which transform hierarchical structures into linear strings. There is no reason why functional-syntactic and hierarchical information could not remain available during further phonological processing (cf. Cooper, Lapointe & Paccia, 1978; Nespor & Vogel, 1982).

2.2 Evaluating the algorithm

The description of the algorithm in Section 1.3 does not evoke a clear image of its overall behavior. Therefore, we find it useful to present here a - somewhat arbitrary - list of features which are characteristic of Basic Intonation Patterns as computed by the algorithm, and of the resulting pitch contours. We start with a discussion of six aspects of Basic Intonation Patterns.

1. Only the end of a major constituent is coded with "/". It follows that intonational phrases may extend over the left side of a constituent but not over the right side (Nespor & Vogel, 1982).

2. The location of a prosodic boundary is intimately related to the presence of a prominent word carrying sentence accent. In (14) for instance, it will not be possible to mark the boundary between direct and indirect object.

(14) ik *verkocht / het boek aan de *leraar #
 I sold the book to the teacher

3. The accent-driven design of the algorithm explains the general observation that the break between subject and predicate constituents has a higher likelihood of being prosodically marked than the break between verb and object. Pitch accents are less frequently assigned to verbs than to nouns. This implies, in general, that (15) will be a better BIP than (16). So, the effect can be explained in terms of (conceptually and/or pragmatically based) assignment of sentence stress and need not have a syntactic origin.

(15) *subject / verb *object #
(16) subject *verb / *object #

4. Within major constituents no boundaries are marked, except for the cases handled by rule B (Section 1.3.1). So, within the major constituents of (17), no further structuring will be indicated. It follows that within subordinate clauses no major constituents can be marked either, except again for the cases handled by rule B (see 18)). The few examples in the literature on unacceptable markings almost always concern boundaries within subordinate clauses (de Rooy, 1979: 133; 't Hart, 1981). This indicates that, in Dutch, these spots are at least problematic. Whether our abolishment of prosodic boundary marking within subordinate clauses is justified, is a matter of future research.

(17) (een *kat van *zuiver *ras) (is) (*heel *duur) #
een *kat van *zuiver *ras / is *heel *duur #
a cat of pure breed is very expensive

(18) (mijn vader) (*eist) (dat ik *volgend jaar mijn *diploma haal) #
mijn vader *eist // dat ik *volgend jaar mijn *diploma haal #
my father demands that I will get my certificate next year

5. Every boundary between coordinate and/or subordinate clauses is marked by "//", provided (1) they contain at least one prominent word, and (2) the end-of-message-symbol "#" has not been inserted between them. This

remains so after conjunction reduction (see (19)). Clausal parentheticals are marked as well (see (20)).

(19) ik ben *wel / *goed // maar *daarom / nog *niet / *gek #
     I am a good guy but not a crazy one

(20) (*deze winkelier) (dat weet *iedereen) (is) (een *echte *boef) #
     *deze winkelier // dat weet *iedereen // is een *echte *boef #
     this shopowner, everybody knows, is a real crook

In certain cases it is not directly evident that one is dealing with a parenthetical. The adverbial phrase in (21) and (22) may be a structurally tight part of the sentence as in the a-versions, or it may be an independent, inserted part as in the b-versions. Only in the latter case we will hear a so-called "comma-intonation". Our algorithm only generates the a-versions because, in the syntactic input, the adverbials always function as normal major constituents. So far, IPG has developed no special treatment for parentheticals. (Nespor and Vogel (1982) run into a similar problem. Their segmentation rules for intonational phrases assume knowledge about phonological structure.)

(21) (Marie) (komt) (volgens *Jan) (*morgen) #
   a. Marie komt volgens *Jan / *morgen #
   b. Marie komt // volgens *Jan // *morgen #
      Mary comes according to John tomorrow

(22) (de *matroos) (ging) (*zonder *toestemming) (de *wal op) #
   a. de *matroos ging *zonder *toestemming / de *wal op #
   b. de *matroos ging // *zonder *toestemming // de *wal op #
      the sailor went without permission ashore

6. The syntactic trees which IPG generates for restrictive and non-restrictive relative clauses look exactly alike. This implies that the characteristic intonational differences between these clause types must be attributed to different factors. One possibility would be to assume that major constituents with a non-restrictive relative clause always contain more than one prominent word. Applying rule B (see Section 1.3.1), then leads to a prosodic marking (see (23)). This, in turn,

forces us into the assumption that for restrictive relative clauses which are not prosodically marked, either the clause or its antecedent carry a sentence accent but not both (see (24)). Whether this solution is a sound one, remains to be seen. The same argument applies to appositions such as (25) and (26). (For a discussion on accentuation in appositions as they appear in speech repairs, see Levelt and Cutler (1983).)

(23) (de *flat (waar *zij in wonen)) (is) (*erg *duur) #
     de *flat // waar *zij in wonen // is *erg *duur #
     the apartment they live in is quite expensive

(24) (de *flat (waar zij in wonen)) (is) (*erg *duur) #
     de *flat waar zij in wonen / is *erg *duur #

(25) (mijn broer (de *tandarts)) (verdient) (een *hoop *geld) #
     mijn broer de *tandarts / verdient een *hoop *geld #
     my brother the dentist earns a lot of money

(26) (mijn *broer (de *tandarts)) (verdient) (een *hoop *geld) #
     mijn *broer // de *tandarts // verdient een *hoop *geld #

So far the discussion on properties of Basic Intonation Patterns. The following six points have to do with characteristics of pitch contours as computed by the algorithm.

7. Utterances normally start with <pitch> = 0. However, a question may start high (see (27)). This patterns will add a pragmatic overtone (e.g., astonishment), and is restricted to utterances with only one prominent word (Collier & 't Hart, 1978: 31). A similar remark has been made with regard to declarative sentences, where a high start is claimed to lead to a surprise/redundancy intonation pattern (Pierrehumbert, 1981). These cases are not generated by the algorithm.

(27) ? How is it *possible #

Utterances end with <pitch> = 0, if they are not a question and if the

BIP is closed off with the end-of-message symbol "#". [Questions may end with <pitch> = 0 or Ø, and an optional continuation rise 2.] In all other cases, either a rise 2 occurs on the final syllable, or the utterance ends with <pitch> = Ø. The latter endings mark the declarative clause as a non-terminal one, but do not necessarily turn it into a question. They indicate one of two things. Speaker suggests he intends to continue and want to keep his turn in the conversation (see (28) where one expects to hear something like "but"); or speaker implies that the listener may have something to add (see (29) which occasions a response by the dialogue partner).

(28) you may take my *motorbike //

(29) you're here for the *first time //

8. The use of the end-of-message symbol "#" is pragmatically motivated. It need not necessarily occur after every main clause: the symbol is appended at the end of the surface structure when the speaker refrains from prosodically linking the utterance to the following one. A repeated ending of successive sentences with "//" leads to an "intonation of enumerations". It provides cohesive ties within a discourse. However, automatic application can easily lead to errors. This is often observed in reading aloud (Nooteboom & Cohen, 1975).

A speaker may close off a sentence with "#", and yet continue it. In that case the second part will sound as a kind of "after-thought", especially when the resumption occurs after a noticeable pause (see 30). Cutler (1980: 77) presents some more examples.

(30) I *dislike / their *policy # [Why?] because it's *nationalistic #

9. A question like (31), asking for a choice between several alternatives, can be intonated in two ways. It may be "closed", as in the a-version, in the sense that one of the mentioned alternatives has to be chosen. Or it is "open-ended", as in the b-version, suggesting that the listener may come up with a further, non-mentioned alternative. A difference with regard to the computational history of the two versions can explain this difference in intonation and "meaning". We assume the conceptual representation underlying the a-version was handed over to the Lexico-Syntactic Stage all at once. This leads to a compound major constituent and subsequently to the absence of a boundary marker between the conjuncts. In the b-version the conceptual representations of two coordinated interrogative sentences were handed over to the syntactic mechanisms one after another (incremental production). So, the part or tea, is in fact a second, elliptical clause.

(31) a. ? do you want *coffee or *tea #

b. ? do you want *coffee // ? or *tea //

10. A delayed fall B can not occur before "//" or "#" without an interpositioned pitch accent (cf. the restriction that C4 can not follow P1, see Section 1.2). This explains why marking of the NP-VP boundary is overruled by the clause boundary in sentences like (32).

(32) the *professor / has demonstrated // that ...

11. Boundaries indicated by "//" have to be marked prosodically with either a delayed fall B or a continuation rise 2, dependent upon the current value of <pitch> (see (28) and (29)). Boundaries of type "/" present a more complicated picture. In some cases they are to be ignored (see the foregoing remark, no. 10). In other cases they have to be marked (namely, when <pitch> = Ø and LOOK-AHEAD > 1. See (33), where high declination has to be reset on the first major constituent boundary). In many cases, however, type "/" boundaries are only optional. In most hat patterns they have been overlooked by LOOK-AHEAD (see (30)).

(33) de *leerkrachten / hebben *extra *lessen / gegeven #

the teachers have given extra lessons

When <pitch> = 0 a continuation rise may occur on the syllable preceding "/" (see (34)). This pattern is among other things, a function of <distance>. In (35) a marking is more likely than in (34). This type of prosodic marking may occur in infinitive clauses and NP's with post-nominal modifiers where, within the same major constituent, several unaccented words follow the marked word, i.e., the value of <distance> exceeds 1 (see (35) and (36)).

(34) in de *Paasvakantie / ben ik naar *Spanje / geweest #

during the Easter vacation I went to Spain

(35) de *burgemeester van het getroffen dorp / is nog *steeds / *onvindbaar #

the mayor of the stricken village has not yet been found

(36) zonder *vervelend te willen zijn / moet ik *toch / iets *opmerken #

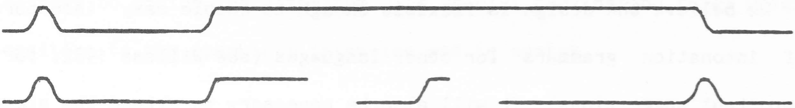
without intending to be nasty, I must tell you something

12. The computed intonation contour does not depend on features of the entire sentence. The auxiliary functions never look beyond the first occurrence of "//" in the current implementation of the model. However, we might assume that, due to speech tempo or emotional state, they may fail to notice certain boundaries. None of the syntactic boundaries is an absolute barrier [8]. E.g., in contour _a_ of (37) both a coordination and a subordination have been missed (and even an accent marker). The contour consists of only two blocks: P1 and E1 (see Table II). Contour _b_ is a 'slow' version and is made up by four blocks: P1, twice C3 and E1. A higher rate of speech will lead to a less variable contour.

(37) *moeder / kwam *toegesneld // en *keek // of ik niets *gebroken had #

a.

b.



mother came rushing towards me and looked if I hadn't broken something

Speech produced by intonation algorithms as the one presented here, is

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[8] All in all, our model, fails to prosodically mark a syntactic boundary in the following circumstances:
1 the boundary does not show up in the BIP (see (14), (17), (18), (24), (25) and (31a);
2 the boundary is recognized, but subsequently discarded as a consequence of applying further rules (see (32));
3 the marking is optional, and application of CHOOSE leads to a free variant without marking (this includes most occurrences of hat patterns, see (30));
4 an obligatory marking is overlooked by LOOK-AHEAD due to extra-linguistic influences (see (37));
5 the sentence is formulated incrementally, and the end-of-message symbol has been inserted too early (see (30)).

usually classified as "neutral" (Pierrehumbert, 1981). We prefer to call it prepared speech. Emotional states and high speech rates will lead to deviative contours which in many cases remain explainable in terms of the algorithm on the additional assumption that, in such circumstances, BIPs may contain omissions (i.e. syntactic boundaries overlooked during contour computation), or non-standard initializations of auxiliary variables (see (27)).

2.3 Concluding remarks

In this paper we have described an algorithm for computing acceptable intonation contours for Dutch sentences uttered in the "prepared speech" mode. In that context, prosodic rules rely more heavily on grammatical control. Therefore, the algorithm will be more successful in predicting which speech utterances are judged correct by native speakers, than in predicting actual speech utterances (cf. de Rooy, 1979).

We believe the design is flexible enough to enable easy incorporation of intonation grammars for other languages (see Willems 1982, for some important suggestions). It will also be necessary to extend the algorithm in such a way that the complete Dutch intonation grammar of 't Hart and Collier can be handled [9].

Two further aspects of prosody deserve special attention in future work on the algorithm.

1. The prosodic organization of an utterance covers not only intonation but also temporal aspects such as segmental lengthenings and pauses.

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[9] Extension of the algorithm can be accomplished in the following ways:
1 by refining the information in the BIP, that is, by throwing away less information from surface syntactic trees;
2 by adding intonation rules or making them more sensitive to context (auxiliary variables); and
3 by making the auxiliary functions more complicated.

Because intonational and temporal markers are highly co-occurrent, rules for these prosodic features should be easy to combine in one algorithm. In fact, it is hardly possible to produce a proper pitch movement without the simultaneous adaptation of the length of the syllable (de Rooy, 1979). Rules for pauses are not much different from those for obligatory boundaries in intonation contours: they are placed on boundaries marked by "//" and "#" (Cooper, 1980).

2. Pitch movements defining an intonation contour are superimposed on a baseline of gradually declining pitch. Declination, which cannot be left out without serious perceptual consequences, is executed largely "automatically". However, the speaker has at least partial control over its course (cf. Cohen, Collier & 't Hart, 1982), hereby manipulating, within limits, the communicative impact upon the listener (e.g., the overall lowering of pitch within certain parentheticals). This will make it necessary to enrich the algorithm with special declination rules which are sensitive to the speaker's intention and to syntax.

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APPENDIX: A partial trace of CONTOUR-COMP

```
Input string: de oude *man / zag *gisteren / deze *vrouw //

Initialize auxiliary variables
   set <pitch>                to   0
   set <mode>                 to   DEC
   set <distance>             to   0
   set <current-symbol>       to   de
   set <next-symbol>          to   oude

enter CONTOUR-COMP
enter PITCH-LOW
    attach 0 to <current-symbol>

set <current-symbol> to oude and <next-symbol> to *man
enter CONTOUR-COMP
enter PITCH-LOW
    attach 0 to <current-symbol>

set <current-symbol> to *man and <next-symbol> to /
enter CONTOUR-COMP
enter PITCH-CHANGE
    attach 1 to <current-symbol> and set <pitch> to Ø
enter PITCH-CONT
enter LOOK-AHEAD
    return 2
enter CHOOSE
    attach Ø to <current-symbol>
enter BOUNDARY?
enter PITCH-HIGH
enter LOOK-AHEAD
    return 2
    attach B to <current-symbol> and set <pitch> to 0

set <current-symbol> to /, <next-symbol> to zag and <distance> to 0

set <current-symbol> to zag and <next-symbol> to *gisteren
enter CONTOUR-COMP
enter PITCH-LOW
    attach 0 to <current-symbol>

set <current-symbol> to *gisteren and <next-symbol> to /
enter CONTOUR-COMP
enter PITCH-CHANGE
    attach 1 to <current-symbol> and set <pitch> to Ø
enter PITCH-CONT
enter LOOK-AHEAD
    return 1
enter CHOOSE
    attach B to <current-symbol> and set <pitch> to 0
enter BOUNDARY?
enter PITCH-LOW
enter LOOK-AHEAD
    return 1
```

```
enter CHOOSE
    attach 0 to <current-symbol>

set <current-symbol> to /, <next-symbol> to deze and <distance> to 0

set <current-symbol> to deze and <next-symbol> to *vrouw
enter CONTOUR-COMP
enter PITCH-LOW
    attach 0 to <current-symbol>

set <current-symbol> to *vrouw and <next-symbol> to //
enter CONTOUR COMP
enter PITCH-CHANGE
    attach 1 to <current-symbol> and set <pitch> to Ø
enter PITCH-CONT
enter LOOK AHEAD
    return 0
enter END?
    return FALSE
enter CHOOSE
    attach Ø to <current-symbol>
enter BOUNDARY?
enter PITCH-HIGH
    attach B to <current-symbol> and set <pitch> to 0


Output-string: de oude man zag gisteren deze vrouw
               0   0   1ØB  0    1B0      0    1 Ø B
```