In the following[1], I will review two accounts of voicing assimilation: that by Hayes for Russian, and that by Booij for Dutch. It will be seen that the use of a privative and articulatory voicing feature coherently accounts for the data in both languages.

The Russian data

Hayes[2] mentions the following data, which the Russian voicing rules will have to describe. Left of the arrows we see the proposed underlying representations, and right of the arrows we see forms that are equal to the phonetic surface forms as far as voicing is concerned. These forms still show, however, the underlying non-reduced vowels and as few palatalized consonants as are needed in an underlying representation. They will, nevertheless, occasionally be referred to in square brackets.

klub-a → *kluba*	*zdorow* → *zdorof*
klub → *klup*	*korow-ka* → *korofka*
mcensk#že → *mcenzgže*	*kriwd* → *krift*
zub-ki → *zupki*	*s wami* → *svami*
wizg → *visk*	*ot wdowy* → *odvdovy*
tri → *tri*	*bez wpuska* → *besfpuska*
pesn' → *pesn'*	*trezw* → *trezf* or *tresf*
žizn' → *žizn'* or *žisn'*	*xorugw'* → *xorugf'*
iz mcenska → *ismcenska*	
ot mzdy → *odmzdy*	
grjob#li → *grjopli*	*zdorow#li* → *zdorovli*

Note that prepositions are cliticized to the following word without a word boundary.

The rules according to Hayes

(1a) *Final Devoicing*

C → [-voice] / __ #

(1b) *Sonorant Revoicing before Sonorant-Initial Clitics*

[+son] → [+voice] / __ # [+son]

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[1] This paper was written for a grad student course that I followed in Groningen in 1989. This was the first time I heard of autosegmental phonology. I added the footnotes in July 1997.

[2] Bruce Hayes (1984): "The phonetics and phonology of Russian voicing assimilation", in a book(?), Ch. 16, pp. 318-328.

(1c) *Deletion of Word-Internal Word Boundaries*[3]
This rule is assumed, though not stated by Hayes.
(1d) *Voicing Assimilation*

"In a consonant cluster, assign the voicing of the last obstruent to all consonants on its left."

(1e) *W strengthening*

$$\begin{bmatrix} \text{C} \\ \text{-cons} \\ \text{+labial} \end{bmatrix} \rightarrow [\text{-son}]$$

(1f) *Sonorant revoicing*

$$[\text{+son}] \rightarrow [\text{+voice}]$$

After having stated (1adef), Hayes invoked rule (1b) in order to account for *zdorow#li* [zdorovli] as opposed to *grjob#li* [grjopli]. It must therefore apply after Final Devoicing and before W Strengthening. ~~It is crucial, though Hayes does not mention the fact, that (1b) be conditioned by a word boundary as it must not be applied to *w+mcenske*, which surfaces as [fmcenske]~~[4]. Therefore, when the derivation reaches rule (1b), the representation still contains word boundaries. Somewhere in the derivation from the underlying representation to the phonetic surface form, however, word-internal word boundaries will have to be deleted. In order not to make the Voicing Assimilation Rule any more complicated than it is, this deletion is best achieved before Voicing Assimilation applies. This means that no pair of rules out of (1a-f) can be put in a different order. To evaluate the ordering, we note that rule (1a) feeds (1b) (well, not really, but it saves (1b) from only being able to apply vacuously) and that (1c) is in a counterbleeding order with respect to (1b). As rule (1c) feeds rule (1d), we conclude that rules (1a-d) are in a natural order. Rule (1e), however, could have fed (1d) and it bleeds (1f). We are accordingly left with two marked orderings.

Let us now have a look at a segmental formulation of the Voicing Assimilation Rule. The parenthesis-star formulation

$$\text{C} \rightarrow [\alpha\text{voice}] \;/\; \_\_ \;(\text{C})^* \begin{bmatrix} \text{-son} \\ \alpha\text{voice} \end{bmatrix},$$

has, according to Hayes, "been fairly well discredited in the literature on other grounds". But if it had not been, the formulation stated would not yield the desired results.The interpretation of (C)* is actually the same as that of C_0, i.e., a simultaneous application of the rule with the substitutions ø, C, CC, CCC, ... (*SPE*, p. 344). In the cluster *zkž*, which is a possible cluster derived by (1a-c) from *zg#ž*, the *z* is simultaneously devoiced by *k* and voiced by *ž*. Furthermore, it is a problem how *k* should then become

[3] Later on, I would have called this *bracket erasue* or *tier conflation*.
[4] Not true. Even /vmcenske/ will be corrected by (1d).

voiced. The heart of the problem lies in the fact that only the rightmost obstruent in a cluster should trigger Voicing Assimilation. The rule can thus be stated as

$$C \rightarrow [\alpha\text{voice}] \; / \; \_\_ \; C_0 \begin{bmatrix} \text{-son} \\ \alpha\text{voice} \end{bmatrix} \begin{bmatrix} \text{C} \\ \text{+son} \end{bmatrix}_0 \begin{Bmatrix} \text{V} \\ \# \end{Bmatrix}$$

Voicing features

Sonorants can be spontaneously voiced (*SPE*, p. 300). With the same laryngeal state, obstruents can be unvoiced. Voiced obstruents need an additional articulatory gesture, say [slack vocal cords]. Thus, unvoiced obstruents are [-slack] and voiced ones [+slack]. Sonorants are not underlyingly specified for this feature, for there is hardly any acoustical difference between $\begin{bmatrix} \text{+son} \\ \text{-slack} \end{bmatrix}$ and $\begin{bmatrix} \text{+son} \\ \text{+slack} \end{bmatrix}$ (a difference of tone, perhaps). Note that it is precisely the underlying [+slack] consonants that are specified for the feature [voice] in Radical Underspecification.

As vowels are pronounced longer than other sonorants, it is easiest to change the laryngeal state as to the value of [slack] during a vowel. This will be a reason for consonant clusters to have the same value of [slack] for all consonants. In Russian we see that a word has to end in [-slack], which causes a word-final obstruent to become unvoiced unless followed by a sonorant, during which the laryngeal state can change from [+slack] to [-slack] (it is probably the return to the respiratory state of spread vocal cords that causes final consonants to lose voicing, but we keep to the [slack] feature since final devoicing is phonologized as in /grjob#li/).

An alternative segmental formulation

In underlying form, all sonorants contain the features $\begin{bmatrix} \text{+voice} \\ \text{-slack} \end{bmatrix}$ and the obstruents are either $\begin{bmatrix} \text{-voice} \\ \text{-slack} \end{bmatrix}$ or $\begin{bmatrix} \text{+voice} \\ \text{+slack} \end{bmatrix}$. Sonorants may become [+slack] during the derivation, and they may retain this feature in the surface phonetic form. It is impossible to have a segment that is $\begin{bmatrix} \text{-voice} \\ \text{+slack} \end{bmatrix}$, so if a rule changes a segment to [-voice], the automatic rule [-voice] $\rightarrow$ [-slack] will apply, and if a segment is changed to [+slack], it will automatically be changed to [+voice].

(2a) *Devoicing before Obstruents and Word Boundaries*

$$C \rightarrow [\text{-slack}] \;/\; \_\_ \left\{ \begin{matrix} \left(\begin{bmatrix} \text{C} \\ \text{+son} \end{bmatrix} \right) \begin{bmatrix} \text{C} \\ \text{-son} \end{bmatrix} \\ \# \end{matrix} \right\} \quad \text{(right to left iterative)}$$

(2b) *Deletion of Word-Internal Word Boundaries*

(2c) *Voicing Assimilation*

$$C \rightarrow [\text{+slack}] \;/\; \_\_ \; C_0 \; [\text{+slack}]$$

(2d) *W Strengthening*

$$\begin{bmatrix} \text{C} \\ \text{-cons} \\ \text{+labial} \end{bmatrix} \rightarrow \begin{bmatrix} \text{-son} \\ \alpha\text{voice} \end{bmatrix} \;/\; \_\_ \; [\alpha\text{voice}]$$

where it is understood that # contains [-voice].

Rule (2a) can be stated the way it is thanks to sonorants being and remaining [-slack] at this stage of the derivation. In contrast with Hayes, who needs to unvoice sonorants, we do not encounter any problems due to the disjunctive ordering that is inherent in the parenthesis notation. Ambiguities pertaining to the use of the α-notation are remedied as well. The Voicing Assimilation rule becomes extremely simple as there can only be one [+slack] segment in a consonant cluster when the derivation reaches (2c). It is therefore a beautiful case for the conjunctive application that is assumed in the C_0-notation.

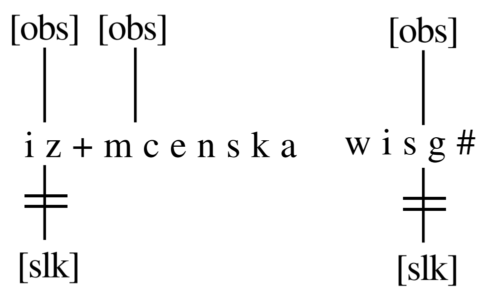
The two sets of rules (1) and (2) are empirically different in that rules (1) predict /zn'#k/ to become [sn'k], whereas rules (2) predict [zn'k].

An autosegmental approach

Rule (2a) must not necessarily be viewed as inserting a [-slack] feature value. As the latter value does not appear in the context of this rule, the action of the rule can equally well be thought of as delinking of a feature value [+slack]. Moreover, only [+slack] spreads according to rule (2c). We will therefore view [slack] as a monovalent autosegmental feature. The autosegments are borne by all obstruent consonants. Independent motivation for this view comes from Japanese, which has an asymmetrical rule that forbids the association of [slack] to more than one underlying obstruent in the morpheme, i.e., there is a synchronic rule that forbids the voicing of *t* in *tokage* in compound formation because *g* bears a [slack] autosegment (though it surfaces as a sonorant).

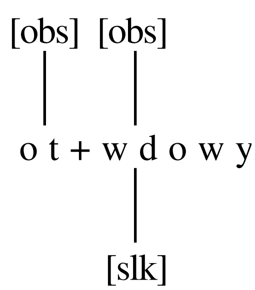
First, we must realize that (2a) is not just a delinking rule, but a phonotactic redundancy rule as well. Some forms of our 'data' must therefore be underlyingly represented as *sdorow*, *msda* and *wisg*. This does not cost us any generality. In what follows, an obstruent that *dominates* a cluster is understood to be the rightmost obstruent in the cluster, unless it is word-final.

(3a) An autosegment [slack] that is linked to an obstruent that does not dominate a cluster, is delinked:

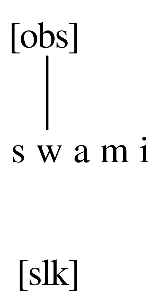


(3b) Word-internal word boundaries are deleted.

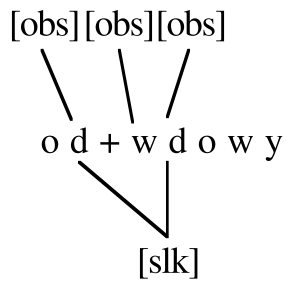
(3c) An autosegment [slack] that is linked to a dominating obstruent is spread to the left:



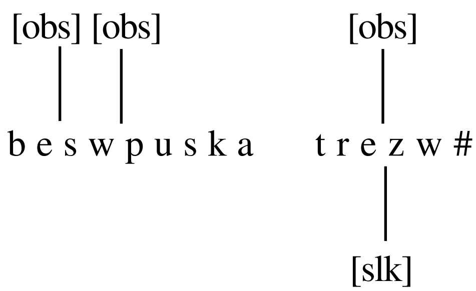
(3d) The segment /w/ becomes an obstruent. We must distinguish two cases: first, /w/ could be in a cluster-dominating position. An autosegment [slack] is then inserted:



Secondly, /w/ could be in a non-dominating position. If there already exists an autosegment [slack] that can link to it, this will happen, even if this involves spreading to the right:



In other cases, /w/ will become voiceless:



Dutch Voicing Assimilation: the data[5]

Automatic:	Optional:
ɣud+s → ɣuts	
ɑsdɔd → ɑzdɔt	ɑf#ded → ɑvdet
tɔb+də → tɔbdə	ɔp#dun → ɔbdun
A.K.Z.O. → ɑkso	ok# #zo → okso
A.B.V.A. → ɑpfa	ɔp#vurən → ɔpfurən
	hɛrfst#blɑd → hɛrfstblɑt *or* hɛrfsdblɑt

The rules according to Booij

G.E. Booij (*Generatieve fonologie van het Nederlands*, Het Spectrum, 1981) mentions the following rules, where $ denotes a syllable boundary:

(4a) *Syllable-final Devoicing of Obstruents*
[-son] → [-voice] / __ $
(4b) *Tautosyllabic Obstruent Devoicing*
[-son] → [-voice] / __ [-son] $

[5] For some reason, I did not show vowel length (perhaps because Booij didn't).

(4c) *Heterosyllabic Progressive Fricative Devoicing*

$$\begin{bmatrix}\text{-son}\\ \text{+cont}\end{bmatrix} \rightarrow [\text{-voice}] \;/\; \begin{bmatrix}\text{-son}\\ \text{-voice}\end{bmatrix} \$ \;\_\_$$

(4d) *Heterosyllabic Regressive Voicing Assimilation before Plosives*

$$[\text{-son}] \rightarrow [\text{+voice}] \;/\; \_\_ \; \$ \begin{bmatrix}\text{-son}\\ \text{-cont}\\ \text{+voice}\end{bmatrix}$$

Rule (4a) feeds (4c) (and (4d) in a certain sense). Rules (4c) and (4d) are not ordered, and (4b) is not ordered with respect to any of the other rules. At word boundaries, Booij gives these two rules:

(4e) *Progressive Fricative Devoicing between Words (Optional)*

$$\begin{bmatrix}\text{-son}\\ \text{+cont}\end{bmatrix} \rightarrow [\text{-voice}] \;/\; \begin{bmatrix}\text{-son}\\ \text{-voice}\end{bmatrix} \#(\#) \;\_\_$$

(4f) *Regressive Voicing Assimilation between Words (Optional)*

$$[\text{-son}] \rightarrow [\text{+voice}] \;/\; [\text{+son}] \;\_\_\; \#(\#) \begin{bmatrix}\text{-son}\\ \text{-cont}\\ \text{+voice}\end{bmatrix}$$

An alternative segmental approach

(5a) *Devoicing before Obstruents, Nasals and Word Boundaries*

$$[\text{-son}] \rightarrow [\text{-voice}] \;/\; \_\_ \left\{\begin{matrix}[\text{-son}]\\ [\text{-cont}]\\ \#\end{matrix}\right\} \quad \text{(right to left iterative)}$$

(5b) *Deletion of Word Boundaries*

This rule is optional.

(5c) *Progressive Fricative Devoicing*

$$\begin{bmatrix}\text{-son}\\ \text{+cont}\end{bmatrix} \rightarrow [\text{-voice}] \;/\; [\text{-son}] \;\_\_$$

(5d) *Regressive Voicing Assimilation*

$$[\text{-son}] \rightarrow [\text{+voice}] \;/\; \_\_ \begin{bmatrix}\text{-son}\\ \text{+voice}\end{bmatrix} \qquad \text{(no iteration)}$$

These rules accomodate a larger set of data than those of Booij do.

Rule (5a) reflects the Dutch phonotactic rule that disallows voiced obstruents before fricatives (in co-operation with 5c-d) and nasals: there are word-initial sequences [fn], [pn], [sn], [xn], [kn], [sm], [ts], [ps], [ks], [sf], [sx], [tj̊], [sj̊] and word-medial [p/t/k/f/s/x + m/n/f/s/x/h/j̊] (ɦ and j pattern as fricatives), whereas there are no words that contain any of their voiced counterparts (Booij gives one apparent exception, /adjø/, which more often than not takes epenthesis as [adijø] or is integrated as [ajy(s)]).

Rule (5c) constitutes the main difference between Russian and Dutch voicing assimilation. It applies to /v, z, ɣ, ɦ, j/. Without it, Dutch would assimilate fairly similarly to Russian, with /ABVA/ surfacing as [ɑbva]. If we remove the analogous rule (4c) from the set (4a-d), however, underlying /ABVA/ would surface as [ɑbfa], which is extremely improbable. This means that rule (5c) can be removed from Dutch grammar or inserted into Russian grammar quite naturally, in contrast with the analogous rule (4c).

Rule (5d) differs from the Russian rule in that it can apply only once in a cluster, transforming the cluster /ds#b/ correctly into [tzb]. Booij derives [tsb], which seems equally right, assuming that voicing starts somewhere inside the second obstruent.

If we disregard the optional rules, the set (5a,c,d) describes more data with fewer rules than does the set (4a,b,c,d), and without any reference to syllable boundaries In order to further evaluate the difference, we remark that the phonotactic constraints imposed by (5a) are not overspecified. Dutch permits word-initial [dw], [zw], [bl], [vl], [ɣl], [br], [dr], [vr] and [ɣr], i.e. clusters of voiced obstruents and all Dutch non-nasal sonorant consonants (these are /w, l, r/; note that /j/ and /ɦ/ are not distinctively sonorant, but that /w/ is, in opposition to /v/; therefore, /j/ and /ɦ/ are allowed to pattern as obstruents, as they actually do). The sets of rules (4) and (5) are now empirically different, as rules (5) allow syllable-final voiced obstruents before /w, l, r/. So we have the words *ablatief* [ɑblatif] and *nabla* [nɑbla] (as opposed to *hopla* [hɔpla]), which show a stressed vowel /ɑ/ that is lax and therefore bears a closed syllable. Rules (4) derive [ɑp$latif] and [nɑp$la], unless it is assumed that /b/ is *ambisyllabic*, which is how Booij would probably view the matter, because [bl] is a possible syllable-initial cluster. However, the cluster [bw] does not appear syllable-initially in Dutch, so from *Zimbabwe* rules (4) derive [zɪmbɑp$wə] (or [zɪmbɑbwə] if the [bw]-gap is considered accidental), whereas rules (5) always derive [zɪmbɑbwə][6].

An autosegmental approach

is quite straightfoward now. In what follows, a consonant that *dominates* a cluster is understood to be the rightmost obstruent or nasal in that cluster, unless it is word-final. Nasals initially bear no [slack] autosegment.

[6] Both pronunciations appeared possible in 1989. My own pronunciation has shifted from [b] in 1989 to [p] in 1997. However, [b] pronunciations have not faded with others. Accidentally, this word violates the constraint against final consonant-sonorant-schwa sequences.

(6a) Every [slack] autosegment borne by a non-dominating consonant is delinked.

(6b) Word boundaries are deleted (optional).

(6c) A [slack] autosegment that is borne by a "fricative", is delinked if this fricative directly follows an obstruent.

(6d) Every [slack] autosegment is spread one consonant to the left.

Of these rules, only (6a) differs from the segmental formulation. Rule (6c) can be understood in the following way: a [slack] autosegment present in the lexicon cannot be linked to the root in certain cases, since this would violate a Dutch phonotactic constraint; as it cannot be associated, this floating autosegment is erased. Therefore, rule (6c) amounts to the interaction of a language-specific well-formedness condition and the universal Stray Erasure rule.

Dutch voicing assimilation need not really involve the feature [slack], as there are no sonority-violating consonant clusters in Dutch, in contrast to Russian. But then, Russian voicing assimilation does not really require that the voicing feature be privative, whereas in Dutch the apparent spreading of [-voice] (throughout the cluster) is asymmetrical compared with the spreading of [+voice] (one segment to the left). The combination, then, of our using a privative and articulatory voicing feature instead of a binary and acoustical voicing feature, allowed us to describe the Dutch asymmetry and the Russian transparency in a coherent manner, involving fewer rules than in Hayes' and Booij's accounts. The approach for Dutch broadened the scope of the rules and rendered any references to syllable boundaries and ambisyllabicity superfluous. Finally, the autosegmental approach for Russian allowed us not to make any reference to unvoiced sonorants.