How DRC 1.2 Differs from DRC 1.0

In this document, the term “DRC 1.0” is used interchangeably to refer to either the DRC model as described in Coltheart et al. 2001, or the software implementation of the model used for that paper. The context should make it clear which meaning is intended.

1. Changes to the Model

The following changes have been made to the DRC theoretical model.

1.1 Phonological Lexicon and Phoneme Layer Interaction

Units in the phonological lexicon are no longer fully connected to all units in the phoneme layer. Each lexical unit now interacts with only enough phoneme sets to account for its phonemes and phonemic word terminator. For example, the unit for /tri/ activates and is activated by the phoneme /t/ in the first phoneme set, /r/ in the second set, /i/ in the third set and the blank phoneme unit in the fourth set. It inhibits and is inhibited by all other phonemes in those sets. There is no longer any interaction between /tri/ and the fifth and following phoneme sets.

Note: The analogous change between the units in the orthographic lexicon and the letter layer was implemented in the DRC 1.1.2+ series, but this change has subsequently been removed.

1.2 Assembly of the Non-Lexical Route’s Input

The process of assembling the input for the non-lexical route, which is performed every cycle after the onset of the route, now halts after the first blank letter. The number of phonemes that the non-lexical route activates on each cycle is consequently limited to the number of phonemes produced by the rules plus at-most one blank phoneme.

Assembly of the input for the non-lexical route no longer uses a fixed number of cycles interval to determine when to add letters. Instead, a new letter becomes available to the route each cycle in which the right-most phoneme set that received excitation from the non-lexical route on the previous cycle contains a phoneme with an activation level that meets or exceeds the value specified by the **GPCCriticalPhonology** parameter.

1.3 ‘Unsupported’ Decay

A new type of decay, known as unsupported decay, has been introduced for the phoneme layer. Unsupported decay works in the same way as normal decay, except that it applies to individual phonemes only on cycles in which they have a net-input of zero or less. For example, if the **PhonemeUnsupportedDecay** parameter is set to 0.05, then every phoneme will experience a 5% decay in its activation level, *subsequent* to the normal decay, on every cycle in which its net-input is zero or less. Note that the effects of decay,

both normal and unsupported, are applied before the effects of net-input (see formula 1 in Coltheart et al., 2001).

1.4 Noise

Finally, noise is now implemented as follows: The amount of noise added to each unit's net-input is determined by an algorithm that produces random numbers with a normal distribution about a mean of zero. Each noise parameter determines the standard-deviation of the distribution for the relevant layer. When a noise parameter is set to zero, noise is disabled for that layer.

2. Implementation Changes

This section covers differences in the implementation of the model that may affect results but do not represent a significant change in the underlying theory of the model. This section is not intended to be an exhaustive list of all such changes. Implementation differences that are disabled by default, or do not lead to different results with the default settings, or are very minor, may not be mentioned.

A bug in the implementation of DRC 1.0 caused incorrect frequencies to be assigned to homophones in the phonological lexicon and homographs in the orthographic lexicon. This has been corrected.

The constant frequency scaling formula (formula 7 in Coltheart et al., 2001) has been modified slightly: one is added to the unit-frequency and the max-frequency-in-lexicon before the common logarithm of each is taken. This is done so that units with a frequency of zero will work correctly.

A change has been made in the way multi-letter GPC rules are handled. In DRC 1.0 a word like ACE might trigger the two rules

- a.e is pronounced /1/
- ce is pronounced /s/

leading to a pronunciation of /1s/. This meant that the E was used by two rules. In DRC 1.2 no letter can be used by more than one rule except as a contextual match.

Decay was not fully implemented in DRC 1.0, but is implemented in DRC 1.2.

3. Parameters

There have been some changes made regarding parameters. One of the most important of these is that inhibition parameters are no longer specified with negative values. Positive values are used instead because the negative nature of the inhibition is already apparent from its name, and the inhibition parameters control the strength of the inhibition, which is a positive concept. Other parameter changes are outlined below.

3.1 Parameter Naming

The current software implementation of DRC 1.2 uses the following conventions for parameter naming:

- The keywords **Feature**, **Letter**, **Orthlex**, **Phonlex**, **Phoneme** and **GPC** are used in the names of parameters that are relevant to, respectively, the visual feature layer, the letter layer, the orthographic lexicon, the phonological lexicon, the phoneme layer and the non-lexical route.
- The names for parameters that control the strength of an excitatory or inhibitory link between layers begin with the keyword for the layer that the excitation or inhibition is coming from. This is followed by the keyword for the layer the excitation or inhibition is going to, and then the type of the connection. Thus **FeatureLetterExcitation** controls the strength of excitation from the visual feature layer to the letter layer, while **PhonemePhonlexInhibition** controls the strength of inhibition from the phoneme layer to the phonological lexicon.
- Parameters that control the strength of inhibition from units in a layer to other units in the same layer contain the word **Lateral**. **PhonlexLateralInhibition**, for example, controls the strength of inhibition that units in the phonological lexicon apply to each other.

3.2 New Parameters

Inhibitory links now exist between the orthographic and phonological lexicons. Two new parameters, **OrthlexPhonlexInhibition** and **PhonlexOrthlexInhibition**, have been created to control the strength of the inhibition. The default values for these parameters are zero, corresponding to behavior identical to DRC 1.0.

The changes to the way the non-lexical route assembles its input have made the parameter that controls the number of cycles before the next letter is accessed (known as **GPCInterletterInterval** in the DRC 1.1.x series) redundant, and it has been removed. The **GPCCriticalPhonology** parameter now replaces it. See the discussion of the changes to the non-lexical route for more information.

Finally, a new parameter called **PhonemeUnsupportedDecay** has been added to control the strength of unsupported decay in the phoneme layer. See the discussion of unsupported decay for more information.

4. Language Specific Data

Data that is language-specific accompanies DRC in files in the Languages directory. There have been substantial changes to this data since DRC 1.0.

4.1 Letters & Phonemes

No changes have been made to the list of letters and their visual features, however a new phoneme, /W/, has been added. See the discussion of the vocabulary for more information.

4.2 Vocabulary

The vocabulary file contains the list of words and pronunciations that are used in DRC's lexicons. It also contains the written frequencies used for frequency scaling in the orthographic lexicon, and spoken frequencies used for frequency scaling in the phonological lexicon (see formulas 6 and 7 in Coltheart et al., 2001.) In DRC 1.0 written frequencies were used for frequency scaling in both lexicons.

A completely new vocabulary file has been derived from CELEX (Baayen et al., 1995) since DRC 1.0. The process used to derive the new data is described in appendix 1.

4.3 Grapheme-Phoneme-Correspondence Rules

The following changes have been made to the rule set. The order of precedence of the rules can be seen in the language-specific 'gpcrules' file.

- All rules that produced the phoneme pair /ju/ now produce the single phoneme /W/. See appendix 1 for more information.
- The context sensitive rules that pronounced the grapheme NG as /N/ when it was followed by a consonant have been changed to apply when the NG is followed by any letter but E. This was the original intention for the rules, but was not possible with the implementation of DRC 1.0.
- The three rules that pronounce the letter W as /w/ at the beginning or in the middle of a string, and as /u/ at the end, have been replaced by a single rule that pronounces W as /w/ at any location in the string.
- The rule that pronounces the letter X as the phoneme pair /ks/ anywhere in the string has been replaced with three separate rules that specify that X is pronounced /z/ at the beginning of the string, and pronounced /ks/ in the middle or at the end of the string.
- The context-sensitive rule that pronounces the letter G as /_/ when it is followed by the letter E has been changed to apply at any location in the string. Previously it only applied at the beginning.
- The context-sensitive rules that pronounce the letter C as /s/ when it is followed by the letter E and occurs at the beginning or in the middle of the string, have been replaced by two rules: (1) SC is pronounced as /s/ when it occurs at the beginning of the string and is followed by one of E, I or Y. (2) C is pronounced as /s/ if it is followed by E, at any position in the string.

The following new rules have been added:

Position	Type	Grapheme	Phoneme	Output-Protected?
Anywhere	Multi-letter	aigh	1	No
Anywhere	Multi-letter	yoo.e	W	No
Anywhere	Multi-letter	yoo	W	No
Anywhere	Multi-letter	yui	W	No
Anywhere	Multi-letter	yeu	W	No
End	Multi-letter	sch	S	No
End	Multi-letter	.ce	s	Yes
End	Multi-letter	.se	s	Yes
End	Multi-letter	.ge	_	No
Anywhere	Multi-letter	yu.e	W	No
Anywhere	Two-letter	bh	b	No
Anywhere	Two-letter	dh	d	No
Anywhere	Two-letter	kh	k	No
Anywhere	Two-letter	uh	V	No
Anywhere	Two-letter	rh	r	No
End	Two-letter	ne	n	No

The following context-sensitive rules have also been added:

Position	Grapheme	Context	Phoneme	Output-Protected?
End	h	Preceding vowel	(none)	No
Beginning	sch	Following letter that is not A, E, I, O or U	S	No
Middle	ue	Preceding letter that is either R, L or S	u	No
End	ue	Preceding letter that is either R, L or S	u	No

Position	Grapheme	Context	Phoneme	Output-Protected?
Anywhere	u.ue	Preceding letter that is either R, L or S	u	No
Anywhere	u.e	Preceding letter that is either R, L or J	u	No
Anywhere	u.e	Preceded by the letters CH	u	No
Middle	que	Followed by either S or D	k	No
Anywhere	u_ue	Any consonant in the '_' position	W	No
Anywhere	a_ue	Any consonant in the '_' position	1	No
End	s	Followed by E	s	Yes
Anywhere	ew	Preceded by either L, R or J	u	No
Anywhere	ey	Preceded by the letters CH	u	No

4.4 Default Parameter Value Changes

The default values for the parameters are part of the language-specific data in DRC 1.2. The table below lists the changes made to the default parameter values since DRC 1.0.

Parameter	DRC 1.0 Name	DRC 1.0 Value	DRC 1.2 Value
GPCOnset	Cycles before route begins	10	26
GPCPhonemeExcitation	GPC to phoneme excitation	0.055	0.051
LetterOrthlexInhibition	Letter to orthographic inhibition	0.435	0.48
MinReadingPhonology	Reading-aloud criterion	0.43	0.4
OrthlexPhonlexExcitation	Orthographic to phonological excitation	0.2	0.25
PhonemeLateralInhibition	Phoneme to phoneme inhibition	0.15	0.147
PhonlexOrthlexExcitation	Phonological to orthographic excitation	0.2	0.25
PhonlexPhonemeExcitation	Phonological to phoneme excitation	0.14	0.09

Appendices

1. Derivation of DRC 1.2's Vocabulary

The DRC vocabulary contains the spellings (field 1), pronunciations (field 2), written-word frequencies (field 4) and spoken-word frequencies (field 5) of 8031 monosyllabic words extracted from file EPW.CD of the CELEX CD (Baayen et al., 1995). The vocabulary was constructed as follows.

From EPW.CD, the spellings (field 2 of EPW.CD) and pronunciations in CELEX's DISC phonetic alphabet (field 7 of EPW.CD) of all monosyllabic items (those without a hyphen in field 7 of EPW.CD) were selected. The words "ahem", "cos k@s" "hem F" and "ugh", were then discarded due to the unusual phonemes in their pronunciations. "Pshaw" was also discarded on the grounds that there are no other words with an initial PSH and it is an exclamation rather than a real word with a meaning. "Y" was discarded as it isn't a word. "Cure", "cured", "cures", "fuel", "fuels", "fuelled" and "pure" were also discarded as, according to the Macquarie Dictionary, they are not monosyllabic in Australian English. "Dos", "E", "Hes", "Mus", "O", "Pis" and "Pos" were discarded as, according to the Macquarie Dictionary, they are not words. "U" was also discarded as it is not a word. Abbreviations etc., were then removed by discarding all items whose spelling contained no vowels (counting y as a vowel) or contained any character that was not a lowercase letter of the alphabet. The abbreviations "oz 6ns" and "yd j#dz" were also removed. The very unfamiliar low-frequency foreign words "djinn", "schist", "tsar" and "czar" and their plurals were deleted on the ground that we did not consider that these would be recognized as words by typical subjects in experiments on reading. Capitalised words for which there was no lowercase equivalent already in the vocabulary (e.g. Thai) were re-added.

Written and spoken word frequences (fields 8 and 11 of EFW.CD) were then obtained by matching each entry obtained from EPW.CD with its counterpart from EFW.CD. The frequencies were summed for duplicate entries (i.e. entries which matched in both spelling and pronunciation) so that there was only one written and spoken frequency for each unique spelling/pronunciation pair.

The single quote characters (stress markers) were removed from the word phonetic transcriptions, as was every /R/. All /$/ phonemes were changed to /9/. For the words cruel and gruel, the /9/ was changed to /u/. For the words blanch, blanched, branch, branched, chance, chanced, chant, chants, dance, danced, france, glance, glanced, grant, grants, graph, graphed, graphs, lance, lanced, plant, plants, prance, pranced, ranch, slant, slants, stanch, stanched and trance the /#/ phoneme was changed to /{/. Finally, all occurrences of the phoneme pair /ju/ were changed to the single, new phoneme /W/, based on the following reasoning:

"The last diphthong, [ju] as in "cue", differs from all the other diphthongs in that its more prominent part occurs at the end. Because it is the only vowel of this kind, many books on English phonetics do not even consider it as a phoneme; they treat it as a sequence of a consonant followed by a vowel and symbolize it by [ju]. I have considered it to be a diphthong because of the way it patterns in English. Historically, it is a vowel, just like the other vowels we have been considering. Furthermore, if it is not a vowel, then we have to say that there is a whole series of consonant clusters in English that can occur before only

one vowel. The sounds at the beginning of "pew, beauty, cue, spew, skew" and (for most speakers of British English) "tune, dune, sue, Zeus, new, lieu, stew" only occur before /u/. There are no English words beginning with /pje/ or /kj{/, for example. In stating the distributional properties of English sounds, it seems much simpler to recognize /ju/ as a diphthong and this reduce the complexity of the statements one has to make about the English consonantal clusters."

-- P. Ladefoged, A Course in Phonetics, 1975, pp 77-78.

References

Baayen, R.H., Piepenbrock, R., & Gulikers, L. (1995). The CELEX Lexical Database (CD-ROM). *Linguistic Data Consortium*, University of Pennsylvania, Philadelphia, PA.

Coltheart, M., Rastle, K., Perry, C., Langdon, R. & Ziegler, J. (2001). DRC: A Dual Route Cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*, 204-256.