TADA (TAsk Dynamics Application) manual

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Description

The core of TADA is a new MATLAB implementation of the Task Dynamic model of inter-articulator coordination in speech (Saltzman & Munhall, 1989). This functional coordination is accomplished with reference to speech **Tasks**, which are defined in the model as constriction **Gestures** accomplished by the various vocal tract constricting devices. Constriction formation is modeled using task-level point-attractor dynamical systems that guide the dynamical behavior of individual articulators and their coupling.

This implementation includes not only the inter-articulator coordination model, but also

- a planning model for inter-gestural timing, based on coupled oscillators (Nam et al, in prog)
- a model (GEST) that generates the gestural coupling structure (graph) for an arbitrary English utterance from text input (either orthographic or an ARPABET transcription).

Functionality

TADA implements three models that are connected to one another as illustrated by the boxes in Figure 1.

1. **Syllable structure-based gesture coupling model**
   Takes as input a text string and generates an *intergestural coupling graph*, that specifies the gestures composing the utterance (represented in terms of *tract variable* dynamical parameters and articulator weights) and the coupling relations among the gestures' timing oscillators.
2. **Coupled oscillator model of inter-gestural coordination**
   Takes as input a coupling graph, and generates a *gestural score*, that specifies activation intervals in time for each gesture.
3. **Task dynamic model of inter-articulator coordination**
   Takes as input a gestural score and generates the motions of the vocal tract constriction variables and the articulatory degrees of freedom.

The time functions of the model's articulatory degrees of freedom are then used to compute a time-varying vocal tract area function (using CASY, Configurable Articulatory Synthesis) and the resonance frequencies and bandwidths corresponding to those area functions. The formant and constriction variable time functions can then be input to the **HLsyn** synthesizer to generate acoustic output. HLsyn can be purchased from Sensimetrics (http://www.sens.com/hlsyn).

As shown by the ☞ in Figure 1, explicit input can be provided for each of the TADA models, so that they can run independently of one another. In addition to running the models on input files, TADA provides graphical display of the model inputs and editing capabilities for the gestural score input.

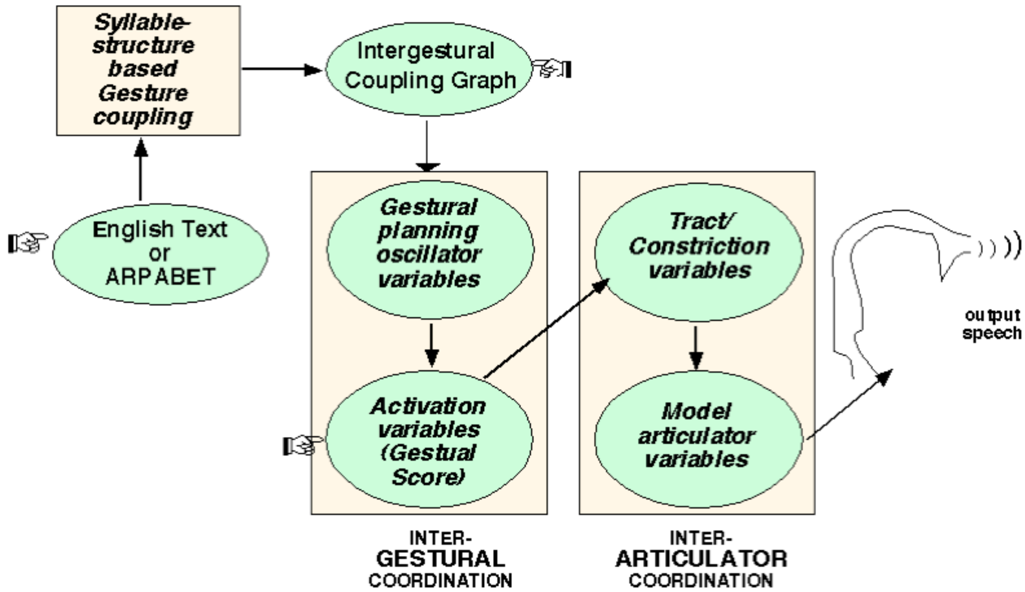


Figure 1. Information flow through TADA models.

Input files

(See appendices for more information about the precise format of these files).

Gestural score

TV<id>.g	Names of gestural score files must begin with 'TV' and have the extension '.g' <id> may be any alphanumeric string that identifies the utterance

Coupling graph

TV<id>.o	contains gestural specifications
PH<id>.o	contains timing oscillator and coupling specifications

Both files must exist and <id> must be the same for both.

Input dialog both allows selection of either TV<id>.g or TV<id>.o files. If a TV<id>.o file is chosen then a matching PH<id>.o file must also exist.

The coupling graph files can be generated automatically from text input. See the **GEST** menu below.

Usage

Launching TADA

- MATLAB™ version: Release 14 (Ver. 7.0 or higher)
  Type 'tada' in command line in MATLAB™.
- Stand-alone version: Double-click on TADA icon.

The TADA Window

TADA opens the GUI shown in Fig. 2.

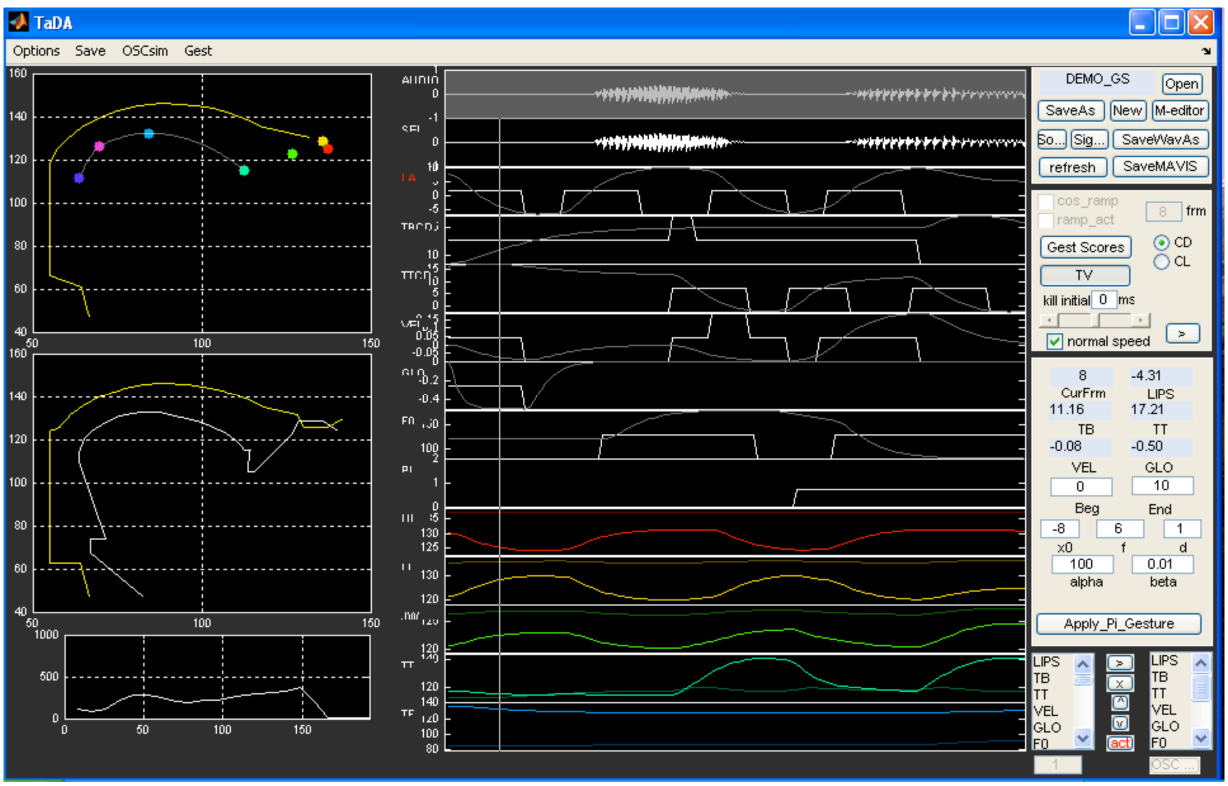


Figure 2.

- In the center is the **temporal display**: the gestural activations that are input to the task dynamic model (gestural score) and time functions of tract variable values and articulator that are the model outputs.
- At the left side is the **spatial display**: vocal tract shape and area function of the at the time of the cursor in the temporal display.
- The right side is organized into four panels of buttons and readouts. From the top, they are:

1. File manipulation buttons
2. Program action controls
3. Numerical readouts (and one Action button)
4. Time function layout editor

Opening Files

Click **[Open]** and select a TV file (TV<id>.g for gestural scores and TV<id>.o for coupling graphs) in the utterance in a selection dialog box. The file <id> will be displayed in the grey text box at the top right. Gestural scores are now displayed. Note that when you open a coupling graph file, the coupled oscillator model is run automatically, and it will take some time for the resulting gestural scores to appear. (NOTE: the coupled oscillator simulation does not neccessarily give a unique solution to the relative phasing of gestures. Thus, opening the same file multiple times can give different results, as the initial conditions of the simulation are, in part, randomly chosen. However, the solutions will be quite dramatically different, and it should be obvious which one is desirable. To insure the same (good) solution can be found again, use the **Save final phases as initial** from the save menu (see below)).

When a gestural score file is opened, TADA is in GESTURAL SCORE MODE, which allows various forms of editing. When a coupling file is opened, TADA is in COUPLING GRAPH MODE, in which oscillator information can be displayed along with the gestural score, but editing is disabled.

If a sound file already exists for that <id> (.wav), it will automatically be displayed. If there is more than one, you will be prompted to select.

Click **[SigOpen]** to input an externally generated sound file that will be displayed and can be played. For example, this function can be used to display waveforms synthesized in HLSyn.

Click **[New]** to open a new TADA window

Running the task dynamic simulation and CASY

When a file has been loaded and the gestural score is displayed, the **[Gest Scores]** button in the Actions panel will be depressed. In this mode, a gestural score can be edited. To shift to run mode, depress the **TV** button. After the computation is complete, time functions of the output are displayed (see below).

Click in the temporal selection panel (2nd from top) to get a cursor. The spatial plots will show an vocal tract information (top-left and mid-left) as well as an area function (bottom-left) at the time indicated by the horizontal location of the cursor. The colored dots in the top plot represent the spatial position of points on the controlled articulators. The middle plot shows the full midsagittal shape as generated by the vocal tract model (CASY). The bottom plot displays the area function of the vocal tract, computed from the 2-D articulatory shape.

From the area functions, formant resonance frequencies and bandwidths are calculated, and these are used to generate an acoustic waveform using a fixed voiced source. This waveform is shown in the top and mid temporal display panels, and can be played by clicking the **[Sound]** button. The output is not the full predicted acoustics of the utterance just its resonance pattern. It does not include any nasalization or any source control (friction, aspiration f0). To generate the full model acoustics, a file called <id>.HL is generated automatically that includes the time functions of the constriction degree tract variables (Lip, Tongue Tip, Velic, and Glottal Apertures), f0, and the first four computed formants. These can be use as control parameters for the HLsyn (Pseudo-articulatory) synthesizer. (Make sure the **generate HLsyn input** in the **Options** menu is checked). <id>.HL can be directly imported in HLSyn.

To return to edit mode, click **[Gest Scores]**.

Temporal Display

These display panels show the gestural score, output tract variables, and articulator time functions.

Gestural Scores
By default, the gestural score is displayed in panels 3-8 of the display, just below the acoustic plots in the top two panels. The gestural scores are displayed as activation functions. Those based on TV<id>.g input files are step functions (activation = 0 or 1), although ramped activation can also be applied. Each box corresponds to the control of a single gesture on the task (constriction) variable. The task variables are:

- Lips — Lip Aperture (LA) — Lip Protrusion (PRO)
- Tongue Body — Constriction Degree (TBCD) — Constriction Location (TBCL)
- Tongue Tip — Constriction Degree (TTCD) — Constriction Location (TTCL)
- Velum — Velic Aperture (VEL)
- Glottis — Glottal Aperture (GLO)
- F0 — F0

The Lips, Tongue Body, and Tongue Tip constrictions are specified for two possible dimensions (**CD** and **CL**) and the display can be toggled from one to the other with the radio buttons with those names in the Actions panel.

More than one gesture may control a given tract variable at a given time, in which case the gestural activations overlap. In the display, this shows up as an activation value of 2, during the region of overlap. (In some more complex utterances more than 2 gestural activations can overlap, but their display is not currently supported).

When clicking in a gestural "box", the values of the dynamical parameters controlling that gesture are displayed in the Readout panel (X_o, natural frequency, and damping ratio of the TV dynamics, and the blending parameters alpha and beta). The beginning and end frames of activation are also shown (default frame rate is 10ms).

When gestures overlap, clicking in lower section of the box will show the parameters of the earlier gesture, clicking in the top will show the later gesture.

Coupling Graphs
When opening a coupling graph file, the gestural score is displayed. The coupling graph itself can be displayed by clicking on the **OSC** button in the Layout panel (only in COUPLING GRAPH MODE) . This

will display a network of lines connecting the gestures, representing the coupling associations which exist between them. Clicking on a link will bring up information about that pair of planning oscillators: their target relative phase, coupling strength, and output relative phase.

Time functions

After running the model, time functions of various variables can be displayed. By default, the tract variable time functions are displayed at the top, superimposed on the activation values (gestural score) for the corresponding tract variable. The **CD** and **CL** radio buttons also toggle the time functions. The numerical values of these time functions (except f0) for the current cursor location are displayed in the Readout panel.

Other time functions displayed by default:

PI gesture (see below)

Articulator positions corresponding to the dots in the top spatial display:

- Upper Lip (UL - red)
- Lower Lip (LL - yellow)
- Jaw (JW - green)
- Tongue Tip (TT - aqua)
- Tongue Body Rear (TR - pink)

Other variables can be displayed. You can select them using the layout panel. Select one from the list on the left, then click the > button to move it to the display list on the right (Select multiple variables using the shift key). Click the **[act]** button to activate the new display. To remove a variable from the display list, select its name then click the **X** button. To reorder, select a variable and use the arrowhead buttons.

Other parameters that can be displayed (time function layout editor, bottom right) include the formant frequencies and the model articulator degrees of freedom:

- LX lip protrusion
- JA jaw angle
- UY upper lip vertical displacement
- LY lower lip vertical displacement
- CL tongue body length
- CA tongue body angle
- TL tongue tip length
- TA tongue tip angle
- GW glottal width
- NA velic opening

Zooming

You can change a selected display range by clicking in the top panel (full waveform) and dragging the edges of the stretchy gray box, or sliding the whole box. The second panels, and all the time functions, will be refreshed with the selected view.

Animation

Click the **[>]** button in the Action panel to watch the articulatory shapes change over time, as the synthesized sound plays synchronously. (The first time you click, the time require by the sound and display is calibrated, so synchronization will not be observed on the first press). When the **normal speed** check-box is unselected, you can control the speed at which the movie displays by adjusting the horizontal slider bar.

Editing

To edit the parameter values in the gestural score, make sure the **[Gest Score]** button is selected. Only gestural scores from TV<id>.g files can be edited. To edit a gesture score computed from a coupling graph, first save the computed gestural score using **[Save As]**.

There are three ways to edit a gestural score:

1. **Editing TV files manually using Matlab built-in editor (when running in Matlab)**
   Use the **M-editor** button in the file panel. (Make sure to save it after editing).

   The M-editor button does not function in the stand-alone version and will produce an error. But the files and plain text and can be edited in any text editor.

2. **Editing using Readout boxes**
   Select a gesture by shift-clicking in its box. A blue outline will appear. The control parameter values (including activation beginning and end) will be displayed in the panel at the right where they can be edited. After editing a parameter value, press <enter> to change the value for the simulation. Double-click elsewhere in the display to de-select the gesture.

   Any changes made in this manner will only be temporary - they will not be saved in the original file. To save the modified vales, click on **[Save As]** in the file panel.

3. **Graphical Editing**
   To **add** a gesture, ctrl-click (or right-click) on the desired tract variable panel and select **add gesture** from the pop-up menu.

   To **delete** a gesture (or gestures) select them using shift-click (multiple gestures can be seleted). Now ctrl-click (or right-click) on a gesture and select **delete gesture** from the pop-up menu.

   To **slide** a gesture (or gestures) in time, first select a gesture by shift-clicking it (multiple selection is allowed.) Move by clicking and dragging the box inside. Double-click elsewhere to de-select.

   To **shrink or expand** the activation of a gesture, shift-click to select it. Change the beginning and end times by clicking and dragging the ends of the box.

   For all temporal edits (either graphical or using readout boxes), if you want changes to apply to both CD and CL tract variables, make sure the **Apply2OtherTV** option is selected in the Options menu.

As with changes made in the readout boxes, any graphical edits are temporary. You will need to save any changes made by using the **[Save As]** button in the file panel.

In addition to editing parameter values, the behavior of the model can be modified through activation ramps and prosodic (pi-) gestures. Like other forms of editing, these can only be performed in GESTURAL SCORE MODE, that is, when working a gestural score from a TV<id>.g file.

Ramps
To add ramped activation, check the **ramp_act** box in the Action panel and specify the number of frames for ramp duration in the text input box to the right of the checkbox. To make a cosine-shaped activation ramp, select the **cos-ramp** checkbox.

Pi-Gestures
Pi gestures specify how the system clock is locally slowed in proportion the pi-gesture magnitude. To apply this slowing, click the **[Apply_pi_Gesture]** button in the readout panel. A window with a modified gestural score will pop up, and a temporary filename beginning with '~' will appear in the text box in the file panel. This file is also temporary. If you close the new window, all changes will be lost. Any pi-modified gestural scores must be saved using the **[SaveAs]** button.

Saving Files

SaveAs button
This saves the currently edited gestural score to a new TV<id>.g file. This function should always be used to replace any temporary files created after applying PI gesture. (You are advised not to use SaveAs after pi-gesture computation for ramped activation gestures because begin and end points are vague after the process).

This function should also be used to save the gestural score generated from a coupling graph (TV<id>.o) file to a gestural score file. Only after saving to a .g file can a gestural score calculated from a coupling graph be manually edited.

saveMAVIS button
After **TV** computation (resulting from clicking the **[TV]** button), click the **[saveMAVIS]** button to save the gestural score and output time functions in .mat file format for use with **MAVIS** or **MView** software packages. Filenames ending with **_mv** may be used with the **MView** software package.

SaveWavAS button
Saves the current audio data as a sound file in .wav format.

Options menu

Changes to settings in the menu are automatically stored for *TADA.ini* and will be in effect when TADA is restarted.

Low Graphic
If checked, this will simplify animation so it can run on systems with slower graphics. Check if you

experience slowdown while displaying animation.

Proportional Freq to Act Interval
If checked, frequency parameter of a gesture changes anti-proportionally when the activation duration of a gesture is changed.

Generate HLsyn input
Automatically generate a .HL file after **TV** computation, which can be input to HLsyn™.

Apply2OtherTVs
If checked this will apply any editing change made to a temporal parameter (Activation or frequency) to both paired CD and CL tract variables.

Plot relative phases
If checked, time functions of relative phases are plotted when the computation for coupled-oscillator model is completed in coupling graph mode.

Save Menu

Save final phases as initial
Saves a new PH<id>.o file with current final oscillator phases in the simulation as the initial conditions in the PH<id>.o file. Useful for a file in which the final phases solution is not unique.

Save Oscillator Simulation
After running the coupled oscillator simulation, this will generate a Matlab structure variable named OSC and save it to the file OSC.mat. The structure includes identifiers, ramp phases, beginning frame, ending frame, inter-oscillator frame difference, gestural activation, final relative phase, angular frequency (omega), generalized relative phase, initial phase, cycle duration, escapement, initial amplitude, inter-oscillator coupling strength, inter-oscillator standard deviation of relative phase, peaks, and final phase. For advanced users only.

Save Activation as Gestural Score
Same functionality as [**Save As]** button (see above).

Save Waveform
Same functionality as **[SaveWavAs]** button (see above).

Save Trajectories
Same functionality as **[SaveMAVIS]** button (see above).

Duplicate
Will make a clone of the TADA window that can be saved as a graphic object or printed.

OSCsim menu

Set Oscillator Sim Noise
Set noise parameters for random noise added to coupled-oscillator simulation. An input dialog box

will pop up showing noise magnitudes for task-level, component-level, and frequency (detuning) noise, and a number indicated which simulation type, that is, which of these three noise types should be added. Currently, only component-level noise has been tested, which is added to acceleration (system force) of individual component oscillators. Noise is sampled from a normal gaussian distribution with zero mean and unit variance. The magnitude of noise can be manipulated in the second element in the box, and **simulation type** should be set to 2.

Set OSC Sim parameters

Set simulation (ODE) parametes for coupled oscillator model. (See MATLAB™ help for more details of ODE parameters.)

GEST menu

Run

This allows text string to be entered from which a coupling graph is automatically computed. A pop-up menu will prompt for output file <id> and path, and then a dialog box in which the following fields can be entered:

- text string (no quotes) -- This can either be English orthography (for existing words) or ARPABET (for nonsense words). If ARPABET is used, it must be in all caps and syllabification must be explicitly represented by enclosing each syllable in parentheses. Word strings can be input with words delimited by '#'. Orthography and ARPABET can be mixed in the same string.
- name of output file <id> (optional)
- name of language (optional) default = *english*
- Prefix for name of the gestural dictionaries and coupling file to be used (optional). Default dictionaries are as follows:
    - *tada/gest/english/seg2gest.txt*
    - *tada/gest/english/gparams.txt*
    - *tada/gest/english/onsets.txt*
    - *tada/gest/english/codas.txt*
    - *tada/gest/english/coupling.ph*

  The function of these dictionaries is described in Appendix II.
  If a <prefix> name is entered in this field, TADA will look in the current directory for any files called *<prefix>seg2gest.txt*, *<prefix>coupling.ph,* etc. This allows user to substitute alternate dictionaries for any or all of the required ones.
  N.B. If you add a prefix, then you must also explicitly type `english` **in the language field.**

IMPORTANT: Current limitations on automatic coupling graph generation:

- The automatic algorithm has been designed to generate acceptable output for a variety of (English) syllables with one or two consonants in onset and/or coda. Inputting a form with three onset or coda consonants will generate output, but there are known problems that may arise.
- The coupling graph is devoid of any prosody or stress. The output should correspond to a sequence of stressed monosyllables, with no intonation. These will be developed in future models. Meanwhile, it is, of course, possible to save the gestural score and edit it to add prosody through use of f0 gestures and pi-gestures. An example is presented in the appendices.

Appendix I. Coupling Graphs

The coupling graph of an utterance is specified in a pair of files:

- *TV<id>.o*
  includes a list of the constriction gestures in the utterance and for each, the values of its control parameters and a label specifying the oscillator (in the paired *PH<id>.o* file) that triggers that gesture's activation.
- *PH<id>.o* file
  includes a list of oscillators and for each, its label, dynamical parameter values, and the phases at which it triggers a gesture's activation and de-activation. It also includes a list of oscillator pairs, specifying the coupling parameters for that oscillator pair.

Each gesture in the *TV.o* file must have a label that corresponds to an oscillator label in the *PH.o* file. More than one gesture may share the same oscillator (in which case their activations will be precisely synchronous). Every oscillator in the *PH.o* file must be coupled to at least one other oscillator.

These files can be constructed by hand. The files are plain text files that can be edited. The demo files presented here (*TVdemo.o, PHdemo.o*) were generated automatically by the GEST command, according to the principles described in Appendix 2. The input utterance was *tip ten*, specified in as input string to GEST as `'tip#ten'`.

TV.o Files

TVdemo.o is shown in Table I.1.

Lines preceded by `%` are comments. The comments in this file were automatically generated by GEST. Looking at these comments, note that in the automatically generated and syllabified ARPABET transcription of the utterance, for example `(T-IH1_P)` for *tip,* hyphen '-' is used to delimit onset from rime, and underscore '_' is used to delimit nucleus from coda. (See Table II.1 for ARPABET symbols). The number following the vowel symbol represents stress, but is not used in the current implementation.

The two numeric fields at the top represent:
<number of milliseconds per synthesis frame> <last frame>
If *<last frame>* = 0, as here, the synthesis will continue until all gestural activations end.

Lines consisting of '##' divide the file into words.

For the rest of the lines, each corresponds to the specification a tract variable for each of the utterance's gestures. For example, for the onset of the word *tip*, six tract variable specifications are listed. Two are for the TT closure gesture, one specifying the degree (TTCD) the other the location (TTCL) of constriction. Two are for the TT release, one for TTCD, one for TTCL. There is also a glottal abduction gesture (GLO) and a velic closure (VEL).

The space-delimited fields on each line represent the following:

TV_name Osc_ID   target freq damp art_wts alpha beta

OSC_ID is a label that identifies the oscillator in the *PH.o* file that controls the activation of that gesture. The labels can be any text string, as long every gesture has a matching oscillator in the *PH.o* file. Here, however, standard labels are generated that represent the syllable position of the gesture `(ons, v, cod)`, the sequential position of the gesture within the onset or coda (in case of consonant clusters), and the sequential position of the syllable within the utterance. The syntax of this standard label is as follows:

<pos><i>_<typ><j>

where:

pos = `ons, v, or cod`
i = sequential position within onset or coda
typ = timing *type* of the oscillator (discussed in Appendix II. These are used in the automatic generation of the *PH.o* file. Different types of gestures are coordinated by different principles)
j = sequential position of the syllable in the input.

For gestures whose pos = `'v', _`*<typ>* may be omitted, as is the case for the `'v1'` and `'v2'` in this utterance.

Note that more than one gesture may share an oscillator. So in the onset of *tip*, the TTCL and TTCD specifications on the first two lines share the `'ons1_clo1'` oscillator. These specifications are for the two dimensions of the TT closure gesture (this is why timing type is called `clo`). Thus, the activations of these tract variables will be synchronous in the gestural score that will be computed. The velic closure (last of the six lines in this onset) also shares this oscillator and will be activated synchronously with these. Lines three and four specify the TTCL and TTCD values for the release of the TT gesture. They will be activated synchronously with each other, as they share the `'ons1_rel1'` oscillator.

Other fields

target is the target (equilibrium position) value of the TV dynamical regime. Specifications for target are in mm (CD) and degrees (CL—90^{o} is palatal, 180^{o} is pharyngeal).

freq is the natural frequency of the TV dynamical regime in Hz.

damp is the damping ratio of the TV dynamical regime.

art_wts sets the effective weight associated with each of model articulatory degrees of freedom in the TV's functional synergy. The higher the value of an articulator weight, the 'heavier' the articulator, the less it will move in the production of a constriction, everything else being equal. (See main TADA manual for list of names of articulators).

alpha specifies the strength of the gesture when it blends with an overlapping gesture of the same TV-- the higher the value, the greater the contribution of that gesture to a weighted average of gestures' parameter values. An *alpha* of 0 indicates that the gesture participates in additive, rather than averaging blending.

beta should always be set to the reciprocal of alpha (except when *alpha=0*, in which case *beta=0*).

Table I.1: *TVdemo.o*

```
10 0

% Input string:     <tip#ten>
%
%
% Word 1:    tip
% arpabet:   (T-IH1_P)
%
%
% syllable 1: T-IH1_P
%
%    onset cluster = <T>
%    segment 1 [T]:
'TTCL' 'ons1_clo1' 56 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 1 1
'TTCD' 'ons1_clo1' -2 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 100 0.01
'TTCL' 'ons1_rel1' 24 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 1 1
'TTCD' 'ons1_rel1' 11 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 1 1
'GLO' 'ons1_h1' 0.4 8 1 GW=1 0 0
'VEL' 'ons1_clo1' -0.1 8 1 NA=1 0 0
%
%    nucleus cluster = <IH1>
%    segment 1 [IH]:
'TBCL' 'v1' 95 3 1 JA=1,CL=1,CA=1 1 1
'TBCD' 'v1' 8 3 1 JA=1,CL=1,CA=1 1 1
%
%    coda cluster = <P>
%    segment 1 [P]:
'LA' 'cod1_clo1' -2 8 1 JA=8,UH=5,LH=1 100 0.01
'LA' 'cod1_rel1' 11 8 1 JA=8,UH=5,LH=1 1 1
'GLO' 'cod1_h1' 0.4 8 1 GW=1 0 0
'VEL' 'cod1_clo1' -0.1 8 1 NA=1 0 0
##

%
% Word 2:    ten
% arpabet:   (T-EH1_N)
%
%
% syllable 2: T-EH1_N
%
%    onset cluster = <T>
%    segment 1 [T]:
'TTCL' 'ons1_clo2' 56 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 1 1
'TTCD' 'ons1_clo2' -2 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 100 0.01
'TTCL' 'ons1_rel2' 24 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 1 1
'TTCD' 'ons1_rel2' 11 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 1 1
'GLO' 'ons1_h2' 0.4 8 1 GW=1 0 0
'VEL' 'ons1_clo2' -0.1 8 1 NA=1 0 0
%
%    nucleus cluster = <EH1>
%    segment 1 [EH]:
'TBCL' 'v2' 95 4 1 JA=1,CL=1,CA=1 1 1
'TBCD' 'v2' 11.5 4 1 JA=1,CL=1,CA=1 1 1
%
%    coda cluster = <N>
%    segment 1 [N]:
'TTCL' 'cod1_clo2' 56 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 1 1
'TTCD' 'cod1_clo2' -2 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 100 0.01
'VEL' 'cod1_n2' 0.2 8 1 NA=1 0 0
##
```

PH.o Files

PHdemo.o is shown in Table I.2.

The file is divided into two sections, the top section includes information about the parameters of individual oscillators, and how the phases of the oscillators are used to trigger gestural activations. The bottom section specifies the coupling parameters between pairs of gestures. The text string `/coupling/` on a line is required to separate the sections. The top line of each section is an automatically generated comment, documenting the fields required in that section.

Oscillator parameters

'OSC_ID' is an oscillator label that matches some label in the TV.o file.

The next fields, up to the required `'/'`, specify the parameters of the limit cycle regime for that oscillator. The equation for an oscillator *i* is as follows:

$$\ddot{x}_{I,i} = -\alpha_i \dot{x}_i - \beta_i x_i^2 \dot{x}_i - \gamma_i \dot{x}_i^3 - \omega_{0i}^2 x_i$$

NatFreq is the natural frequency, ω_0 , of the limit cycle oscillator expressed in Hz.

m:n is the oscillator frequency expressed as an integer used in the defining of the *m:n* ratio of any oscillator pair, which in turn is used determining their *generalized relative phase*. If the NatFreqs of the two oscillators are not in the same ratio, as *m:n*, detuning and phase wandering will result. The default specifications used by the automatic algorithm sets the *NatFreq* of oscillators corresponding to vowel gestures to 3 Hz, and those corresponding to consonant gestures to 6 Hz. The corresponding *m:n* values are 1 and 2, respectively.

escap is the oscillator escapement, *p*. p is used to compute the alpha, beta, gamma coefficients of the limit cycle oscillator as follows (where ω is the *NatFreq*)

$$\alpha = -\omega \cdot p, \ \beta = \omega \cdot p, \ \gamma = p / \omega,$$

amp_init is the amplitude at time t_0.

phase-init is the oscillator phase at time t_0. Specifying its value as NaN means that a random phase is chosen, except:

V oscillators receive *phase_init* = 0
In a C cluster, phase_init set as follows:
CCV: C1=60, C2=-60
CCCV: C1=45, C2=0, C3=45

Note that other than the difference in frequency between V and C oscillators, all other parameters are, by default, equal.

Activation fields

The fields following the slash (/), *riseramp, plateau, fallramp,* specify the activation and de-activation phases (in degrees) of gestures whose activation is triggered by that oscillator. Gestural activation always begins at phase 0. Activation level is ramped from a value of 0 at phase 0 to a maximum value (=1) at the phase specified as *riseramp*. The activation remains at the maximum level until the phase specified as *plateau*, at which time a falling ramp begins, leading to activation of 0 again at phase *fallramp*.

The default values show that `v` gestures are active for a greater proportion of their oscillator's cycle than `c` gestures, `clo` gestures a greater proportion than their `rel`, and `ons` gestures a greater proportion than `cod` gestures.

Coupling fields

Again, the first line in this section is an automatically generated comment about the structure of the following fields.

The following lines are organized into sections corresponding to the successive onsets and codas in the utterance, though this has been done only for clarity in this documentation. The automatic algorithm does not order the lines in this way (and of course the order of the lines is irrelevant to the calculation of the output).

Each line specifies a pair of oscillator labels *('OSC_ID1', 'OSC_ID2'*), two relative coupling strength (the first is a_{21}, the strength of coupling from osc2 onto osc1, and second is the reverse, a_{12}), and a target relative phase for the two oscillators (ψ_{12}) in degrees.

For example, the first phasing entry:

```
% Syll 1: onset
'ons1_clo1' 'v1' 1 1 0
```

specifies that the `clo` oscillator in the onset of the first syllable is coupled to that syllable's `v` oscillator with a value of ψ_{12}= 0. Thus, in the absence of competition, the final relative phase of these oscillators after the coupling simulation should be equal to 0, and the activation of the corresponding gestures should begin at the same point in time. In this case, that would mean the TT gesture for the /T/ in *tip* and the TB gesture for the /IH/.

The next line specifies that relative phase for the `clo` and `rel` oscillators for the constriction in the onset:

```
'ons1_clo1' 'ons1_rel1' 1 1 180
```

The value of ψ_{12}= 180 degrees. This means that, in the absence of competition, the final relative phase of these oscillators after the coupling simulation should be equal to 180, that is, they are in an anti-phase relation. This means that the activation waves triggered at phase 0 of the two oscillators will not be synchronous -- one will precede the other in time. Since oscillation is continuous, one cycle after the next, the anti-phase specification does not, by itself, deterimine which of the gestures is activated earlier, it depends which cycle of each oscillator does the triggering. The order of gestures on the line is used by the activation algorithm to establish temporal precedence. So in this case, the activation of the gesture triggered by the `clo` oscillator will precede the activation of gesture triggered by the `rel` oscillator.

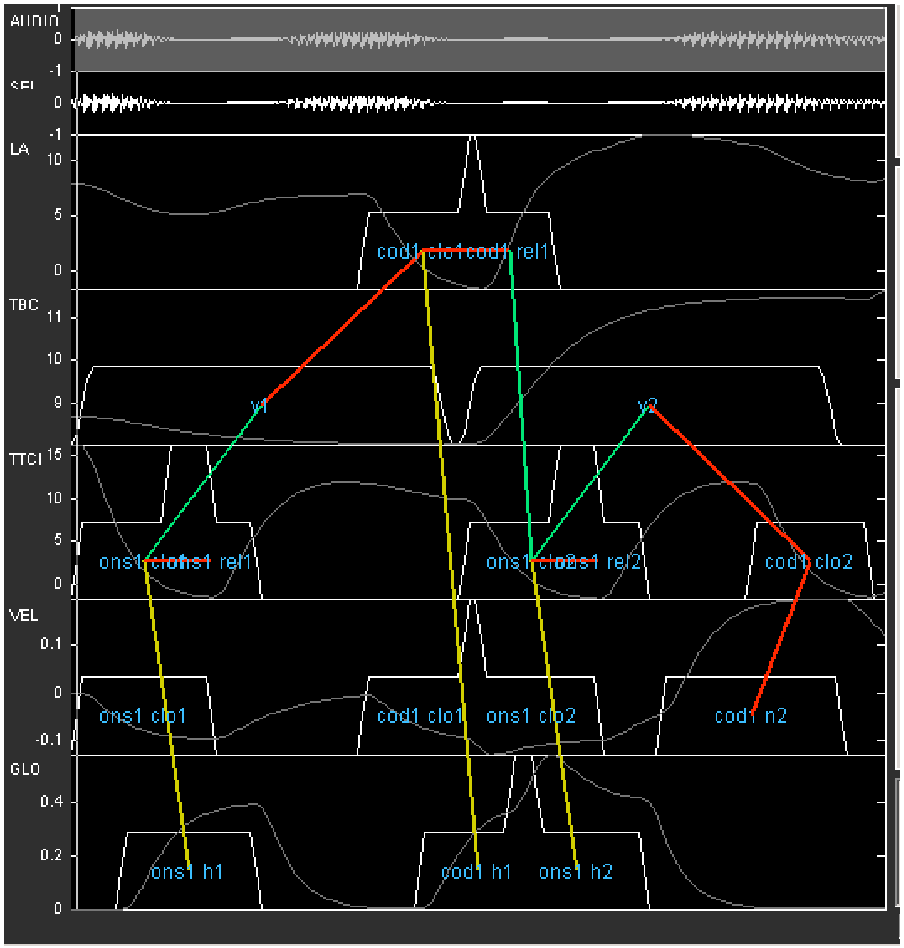
The ψ_{12} specifications in the coupling fields define a graph connecting all the oscillators in the utterance. Every oscillator must be coupled to at least one other one. Multiple coupling links are allowed, and can be used to create competitive coupling, as has been discussed in Nam and Saltzman, 2003; Goldstein et al, 2006; Saltzman et al., submitted.

When a coupling graph is input to into TADA, the corresponding activation intervals will be calculated. If the osc_links button is depressed, these activation intervals are connected with lines corresponding the coupled oscillator pairs. Green represents in-phase coupling (0 degrees), red represents anti-phase coupling (180 degree), and yellow represents some other phase. The coupling graph for *tip ten* is shown in Fig. I.1, superimposed on the output tract variable time functions.

Table I.1: *PHdemo.o*

```
%'OSC_ID' NatFreq m:n escap amp_init phase_init / riseramp plateau fallramp
'v1' 3 1 4 1 NaN / 20 340 360
'v2' 3 1 4 1 NaN / 20 340 360
'ons1_clo1' 6 2 4 1 NaN / 20 250 270
'ons1_clo2' 6 2 4 1 NaN / 20 250 270
'cod1_clo1' 6 2 4 1 NaN / 20 220 240
'cod1_clo2' 6 2 4 1 NaN / 20 220 240
'ons1_h1' 6 2 4 1 NaN / 20 250 270
'ons1_h2' 6 2 4 1 NaN / 20 250 270
'cod1_h1' 6 2 4 1 NaN / 20 220 240
'cod1_n2' 6 2 4 1 NaN / 20 340 360
'cod1_rel1' 6 2 4 1 NaN / 20 160 180
'ons1_rel1' 6 2 4 1 NaN / 20 160 180
'ons1_rel2' 6 2 4 1 NaN / 20 160 180

/coupling/

%'OSC_ID1' 'OSC_ID2' strength1(to OSC1) strength2(to OSC2) TargetRelPhase

% Syll 1: onset
'ons1_clo1' 'v1' 1 1 0
'ons1_clo1' 'ons1_rel1' 1 1 180
'ons1_clo1' 'ons1_h1' 1 1 90

% Syll 1: coda
'v1' 'cod1_clo1' 1 1 180
'cod1_clo1' 'cod1_rel1' 1 1 180
'cod1_clo1' 'cod1_h1' 1 1 90

% Syll 1 - Syll 2
'cod1_rel1' 'ons1_clo2' 1 1 0

% Syll 2: onset
'ons1_clo2' 'v2' 1 1 0
'ons1_clo2' 'ons1_rel2' 1 1 180
'ons1_clo2' 'ons1_h2' 1 1 90

% Syll 2: coda
'v2' 'cod1_clo2' 1 1 180
'cod1_n2' 'cod1_clo2' 1 1 180
```

Figure I.1


AUDIO
SEL
LA
TBC
TTCL
VEL
GLO
cod1 clo1
cod1 rel1
v1
v2
ons1 clo1
ons1 rel1
ons1 clo2
ons1 rel2
cod1 clo2
cod1 clo1
cod1 n2
ons1 h1
cod1 h1
ons1 h2

Appendix II. Automatic Computation of Coupling Graphs

The GEST command (see main manual) provides automatic computation of the intergestual coupling graph associated with an arbitrary input (either english text or ARPABET). These computations are represented by the box labeled **Syllable structure-based gesture coupling model** in Figure 1 of the manual.

Note: while the other models represented by boxes in Figure 1 (**Coupled oscillator model of inter-gestural coordination** and **Task dynamic model of inter-articulator coordination)** are meant to be part of a model of the human speech production process, the method used for automatic generation of coupling graphs is a heuristic that is not meant to model how a speaker would go about construction a coupling graph for an arbitrary form. Coupling graphs could simply be stored by speakers in the lexicon. The automatic computation has two major benefits: (1) It represents in compact form generalizations about the set of coupling graphs that speakers use (in English, at least) and their relation to more conventional phonological representations (segments, features, syllable structure). (2) It allows the later stages of the model to be tested, by allowing automatic generation of a variety input files.

The automatic generation has two components. The first generates a *TV<id>.o* file that include a list of gestures, their positions within syllables, their dynamical parameters, articulator weights, and blending parameters. The second generates a *PH<id>.o* file containing intergestural coupling specifications from the *TV<id>.o* file, using knowledge relating syllable structure to coupling as expressed in the file *TADA/gest/English/coupling.ph*, which can be modified to test hypotheses about this relation

Generating *TV.o*

1. *Creating a syllabified phonetic transcription*. Orthographic input to GEST is converted to a syllabified broad phonetic transcription using ARPABET notation (see Table II.1). This is accomplished by looking the form up in a syllabified version of the CMU English pronunciation dictionary (found in *TADA/gest/english/pdict.txt*). The syllabification (not present in CMU's dictionary) was done by applying a max-onset algorithm checked against an enumerated list of legal onsets. The algorithm starts by treating all Cs between V1 and V2 as the onset cluster to V2. If it can't find the cluster in the list of legal onsets, it will strip off consonants one by one, assigning them to the previous coda, until it finds the longest legal cluster, at which point it inserts the syllable boundary:

    V1 C C)(C C C V2

The example file in Appendix I, Table I.1, *TVdemo.o*, shows the ARPABET transcription of each of the syllables in the test utterance 'tip#ten' in the comments.

2. *Specification of gestural composition*. GEST then looks up each segment of the transcription in a dictionary (*TADA/gest/english/seg2gest.txt*) that gives the gestural composition of each English segment. The information in this and all other dictionaries is saved in spreadsheet form in *TADA/gest/english/gestures_english.xls*). The easiest way to edit the contents of the dictionaries (to create customized versions) is to edit the *.xls* file, then paste into the appropriate dictionaries (as discussed below).

The *seg2gest* dictionary is shown here in Table II.2. The gestures are represented symbolically by four descriptors: Constricting Organ, Oscillator Type, Tract Variable, Constriction Type.

Oscillator Type identifies the timing oscillator that will be associated with this gesture and the kind of inter-gestural coordination relation this gesture will participate in. This information is passed into the TV.o file, and will be used by the component that computes the PH.o file automatically, as discussed below.

Constriction Type is used to assign values of the dynamical parameters, blending parameter, and articulator weights for the gesture.

3. *Assigning gestural parameter values*. The quantitative values for the Tract Variable target, blending parameter (*alpha*), and articulator wts for each gesture are then found in *TADA/gest/english/gparamst.txt,* here shown in Table II.3. Periods '.' shown in the articulator weight fields indicate that the articulator is not used for that TV. In addition to the values in this table, some default values are assigned: TV frequency is set by default to 4 Hz for all gestures associated with **v** oscillator, and is set to 8 Hz for the others. Damping ratio is set to 1. Gestures associated with **v** (or **v-rnd**) oscillator are all assigned the value of 1 for alpha and all the relevant articulator weights.

Segment-level exceptions to the values in the gesture table or the defaults can be specified directly in the segment dictionary, which includes fields for *target, freq, damping, alpha, and art wts*, though mostly they have periods '.' indicating that the values from the gesture table or default is fine. For example, exceptions for *target* can be seen for /Z/ and for *freq* in /JH/.

4. *Exceptions.* By default, the gestural composition of a complex onset or coda is the union of the set of gestural specifications of its segments. In some cases, one or more of the gestures that would be implied by the segmental transcription are not present. These cases are handled by exception rule files for onset (*TADA/gest/english/onsets.txt)* in Table II.4 and codas *(TADA/gest/english/coda.txt*) in Table II.5. The syntax for each line in the table is as follows:

ARPABET C TV Constr

- ARPABET is the string to which the rule applies; may be single C or sequence
- C is the consonant whose gesture is deleted
- TV is the tract variable of the deleted gesture
- Constr is the Constriction Type of the deleted gesture.

For example, the following line in *onsets.txt,* will delete the `GLO WIDE` gesture associated with the segment /P/ in any onset cluster containing the string /SP/.

```
SP     P      GLO    WIDE
```

In addition, the exception rules file can be used to assign a parameter value for an onset or coda that is different from the one obtained from *seg2gest.txt* and *gpararms.txt.* This can be useful for specifying different values in onset and coda. So for example, the following line in *codas.txt* would make produce a glottalization (GLO aperture = 0) gesture for a /T/, instead of an glottal abduction:

```
T      T      GLO    WIDE   0
```

5. *Output.*
Output is a TV.o file (see Appendix I) with the fields:

TV_name Osc_ID target freq damp art_wts alpha beta

Generating *PH.o*

In the automatic generation of coupling graphs, the information coded in the OSC_ID field is used to compute the oscillator parameters and coupling parameters in the PH.o file. The relevant information in this field includes syllable position (`ons, cod, V`), the sequential position within onset and coda, and the oscillator type.

The oscillator types are defined to represent different classes of coupling behavior. The types are sometimes named after the constriction degree of the corresponding gesture, since this is a major determinant of coupling behavior. The coupling classes (oscillator types) are shown in (1) and (2). Classes of consonant oscillators (found in (`ons, cod`) are shown in (1), vowels in (2).

(1)
```
clo crt nar
rel
voc
h
n
```

(2)
```
V
V_round
```

The oscillators (`clo crt nar`) correspond to the primary oral constrictions for stops, fricatives and glides, respectively. Each of these may have (and usually does have) a paired release (`rel`) oscillator. Liquids (/r/, /l/) have a secondary oral constriction, whose type is `voc`. Glottal gestures are associated with the `h` oscillator, and velum lowering with the `n` oscillator. Vowel types are `V` (tongue constrictions) and `V_round` (lip constrictions).

The file that controls the mapping from OSC_IDs to coupling is *TADA/gest/english/coupling.ph,* and it is shown in Table II.6. It can be modified to test alternative hypotheses, and is one of the input files to GEST (See **GEST** command in main manual).

The file has two main sections, corresponding to the two sections of the PH.o file, *oscillator parameters* and *coupling*. The sections are separated by the string `/coupling/`.

The top section specifies the oscillator parameters for OSC_IDs with variables allowed for sequence and syllable numbers. Oscillators in `cod` have shorter activation intervals (in phase) than in `ons`. C oscillators (`clo crt nar voc`) have shorter activation intervals than V oscillators (`v` and `v_rnd)`.

Coupling specifications are divided into three sections: *within-syllable* coupling, *cross-syllable* coupling, and cross-word coupling. The sections are separated by the strings `/cross-syllable/` and `/cross-word/`.

Each line in the coupling section has two OSC_IDs, with position and sequence numbers removed. The algorithm will look for oscillators that satisfy those specifications and will assign a coupling link from the first gesture of the pair to the second. The next three arguments on each line represent the coupling strengths (in each direction) and the relative phase. The oscillator pairs fall into three types:

- C-C each OSC_ID from the set (`clo crt nar)` with distinct sequence numbers
- C-V one OSC_ID from the set (`clo crt nar)` and one `v`.
- Within C one OSC_ID from the set (`clo crt nar)` and one from the set (`rel, voc, h, n`); the sequence numbers of the two oscillators must match.

Note that the specifications for couplings for h are partially ordered. Once an `h` oscillator has been assigned a link, later statements involving that oscillator are ignored.

The syntax and operations of the algorithm using the information in *coupling.ph* is not designed to be general purpose, and adding new coupling links might not work the way you expect. You should be able to change the values of the parameters in this file, however, with no problems. And of course, you can always edit the resulting PH.o file to suit.

Table I.1: ARPABET

P		
T		
K		
B		
D		
G		
M		
N		
NX	= /ŋ/	thing
F		
V		
TH	= /θ/	thing
DH	= /ð/	this
S		
Z		
SH	= /ʃ/	assure
ZH	= /ʒ/	azure
W		
R		
Y	= /j/	you
HH	= /h/	high
CH	= /tʃ/	chew
JH	= /dʒ/	jaw

IY	= /i/	heed
IH	= /ɪ/	hid
EY	= /eɪ/	hayed
EH	= /ɛ/	head
AE	= /æ/	had
AA	= /a/	hod
AO	= /ɔ/	hawed
OW	= /oʊ/	hoed
UH	= /ʊ/	hood
UW	= /u/	who'd
ER	= /ɚ/	herd
AH	= /ʌ/	hud
AY	= /aɪ/	hide
AW	= /aʊ/	how
OY	= /ɔɪ/	boy
AX	= /ə/	about

Table I.2: Gestures assigned to segments

Stops

ARPA	Organ	Osc	TV	Constr	Target	Stiff
B	Lips	clo	LA	CLO	.	.
	Lips	rel	LA	REL	.	.
	Velum	clo	VEL	CLO	.	.
P	Lips	clo	LA	CLO	.	.
	Lips	rel	LA	REL	.	.
	Glottis	h	GLO	WIDE	.	.
	Velum	clo	VEL	CLO	.	.
M	Lips	clo	LA	CLO	.	.
	Lips	rel	LA	REL	.	.
	Velum	n	VEL	WIDE	.	.
D	TT	clo	TTCL	ALV	.	.
	TT	clo	TTCD	CLO	.	.
	TT	rel	TTCL	REL	.	.
	TT	rel	TTCD	REL	.	.
	Velum	clo	VEL	CLO	.	.
T	TT	clo	TTCL	ALV	.	.
	TT	clo	TTCD	CLO	.	.
	TT	rel	TTCL	REL	.	.
	TT	rel	TTCD	REL	.	.
	Glottis	h	GLO	WIDE	.	.
	Velum	clo	VEL	CLO	.	.
N	TT	clo	TTCL	ALV	.	.
	TT	clo	TTCD	CLO	.	.
	TT	rel	TTCL	REL	.	.
	TT	rel	TTCD	REL	.	.
	Velum	n	VEL	WIDE	.	.
G	TB	clo	TBCL	VEL	.	.
	TB	clo	TBCD	CLO	.	.
	TB	rel	TBCD	REL	.	.
	Velum	clo	VEL	CLO	.	.
K	TB	clo	TBCL	VEL	.	.
	TB	clo	TBCD	CLO	.	.
	TB	rel	TBCD	REL	.	.
	Glottis	h	GLO	WIDE	.	.
	Velum	clo	VEL	CLO	.	.
NX	TB	clo	TBCL	VEL	.	.
	TB	clo	TBCD	CLO	.	.
	TB	rel	TBCD	REL	.	.
	Velum	n	VEL	WIDE	.	.

Fricatives

V	Lips	crt	LA	CRIT	.	.
	Lips	rel	LA	REL	.	.
	Lips	crt	LP	DENT	.	.
	Lips	rel	LP	REL	.	.
	Velum	crt	VEL	CLO	.	.
F	Lips	crt	LA	CRIT	.	.
	Lips	rel	LA	REL	.	.
	Lips	crt	LP	DENT	.	.
	Lips	rel	LP	REL	.	.
	Glottis	h	GLO	WIDE	.	.
	Velum	crt	VEL	CLO	.	.
DH	TT	crt	TTCL	DENT	.	.
	TT	crt	TTCD	CRIT	-1	.
	TT	rel	TTCL	REL	.	.
	TT	rel	TTCD	REL	.	.
	Velum	crt	VEL	CLO	.	.
TH	TT	crt	TTCL	DENT	.	.
	TT	crt	TTCD	CRIT	-1	.
	TT	rel	TTCL	REL	.	.
	TT	rel	TTCD	REL	.	.
	Glottis	h	GLO	WIDE	.	.
	Velum	crt	VEL	CLO	.	.
Z	TT	crt	TTCL	ALV	.	.
	TT	crt	TTCD	CRIT	0.16	.
	TT	rel	TTCL	REL	.	.
	TT	rel	TTCD	REL	.	.
	TB	crt	TBCL	VEL	.	.
	TB	crt	TBCD	WIDE	.	.
	Velum	crt	VEL	CLO	.	.
S	TT	crt	TTCL	ALV	.	.
	TT	crt	TTCD	CRIT	.	.
	TT	rel	TTCL	REL	.	.
	TT	rel	TTCD	REL	.	.
	TB	crt	TBCL	VEL	.	.
	TB	crt	TBCD	WIDE	.	.
	Glottis	h	GLO	WIDE	.	.
	Velum	crt	VEL	CLO	.	.
ZH	TT	crt	TTCL	ALVPAL	.	.
	TT	crt	TTCD	CRIT	0.5	.
	TT	rel	TTCL	REL	40	.
	TT	rel	TTCD	REL	.	.
	TB	crt	TBCL	PAL	.	.
	TB	crt	TBCD	NAR	5	.
	Velum	crt	VEL	CLO	.	.
SH	TT	crt	TTCL	ALVPAL	.	.
	TT	crt	TTCD	CRIT	.	.
	TT	rel	TTCL	REL	40	.
	TT	rel	TTCD	REL	.	.
	TB	crt	TBCL	PAL	.	.
	TB	crt	TBCD	NAR	8	.
	Glottis	h	GLO	WIDE	.	.
	Velum	crt	VEL	CLO	.	.

Affricates, Liquids, Glides

JH	TT	crt	TTCL	ALVPAL	.	.
	TT	crt	TTCD	CLO	.	.
	TT	rel	TTCL	REL	50	.
	TT	rel	TTCD	REL	.	.
	TB	crt	TBCL	PAL	.	.
	TB	crt	TBCD	NAR	5	.
	Velum	crt	VEL	CLO	.	.
CH	TT	crt	TTCL	ALVPAL	.	.
	TT	crt	TTCD	CLO	.	.
	TT	rel	TTCL	REL	50	.
	TT	rel	TTCD	REL	.	.
	TB	crt	TBCL	PAL	.	.
	TB	crt	TBCD	NAR	5	.
	Glottis	h	GLO	WIDE	.	.
	Velum	crt	VEL	CLO	.	.
Y	TB	nar	TBCL	PAL	.	.
	TB	nar	TBCD	NAR	.	.
	Lips	nar	LA	V	.	.
W	TB	nar	TBCL	UVU	.	.
	TB	nar	TBCD	NAR	.	.
	Lips	nar	LA	NAR	.	.
	Lips	rel	LA	REL	.	.
R	TT	nar	TTCL	PAL	.	.
	TT	nar	TTCD	NAR	.	.
	TT	rel	TTCL	REL	.	.
	TT	rel	TTCD	REL	.	.
	Lips	voc	LA	NAR	.	.
L	TT	nar	TTCL	ALV	.	.
	TT	nar	TTCD	NAR	.	.
	TT	rel	TTCL	REL	.	.
	TT	rel	TTCD	REL	.	.
	TB	voc	TBCL	UVU	.	.
	TB	voc	TBCD	NAR	.	.
HH	Glottis	h	GLO	WIDE	.	.
Q	Glottis	clo	GLO	CLO	.	.

Vowels

IY	Lips	v	LA	V	.	.
	TB	v	TBCL	PAL	.	.
	TB	v	TBCD	V	5	.
IH	TB	v	TBCL	PAL	.	3
	TB	v	TBCD	V	8	3
EY	TB	v	TBCL	PAL	.	.
	TB	v	TBCD	V	8.5	.
EH	TB	v	TBCL	PAL	.	3
	TB	v	TBCD	V	11.5	.
AE	TB	v	TBCL	PHAR	.	.
	TB	v	TBCD	V	17	.
AA	TB	v	TBCL	PHAR	.	.
	TB	v	TBCD	V	11	.
AO	TB	v	TBCL	PHAR	.	.
	TB	v	TBCD	V	11	.
	Lips	v_rnd	LP	PRO	12	.
	Lips	v_rnd	LA	NAR	5	.
UW	TB	v	TBCL	UVU	.	.
	TB	v	TBCD	V	4	.
	Lips	v_rnd	LP	PRO	12	.
	Lips	v_rnd	LA	NAR	5	.
UH	TB	v	TBCL	UVU	.	3
	TB	v	TBCD	V	6	3
	Lips	v_rnd	LP	PRO	12	.
	Lips	v_rnd	LA	NAR	5	.
OW	TB	v	TBCL	UVUPHAR	.	.
	TB	v	TBCD	V	5	.
	Lips	v_rnd	LP	PRO	12	.
	Lips	v_rnd	LA	NAR	5	.
AH	TB	v	TBCL	UVUPHAR	.	3
	TB	v	TBCD	V	6.5	3
AX	TB	v	TBCL	UVU	.	3
	TB	v	TBCD	V	8.5	3
ER	TT	v	TTCL	PAL	.	.
	TT	v	TTCD	NAR	.	.
	TB	v	TBCL	PHAR	.	.
	TB	v	TBCD	V	11	.

Table I.3 Gestural Specifications

TV	Constr	Target	Alpha	LX	JA	UH	LH	CL	CA	TL	TA	NA	GW	Applicable Segments
LA	CLO	-2	100	.	8	5	1	.	.	.	.	.	.	B, P, M
LA	CRIT	1	10	.	8	5	1	.	.	.	.	.	.	V, F
LA	NAR	2	1	.	8	5	1	.	.	.	.	.	.	W, R, AO, UW, UH, OW, ER
LA	V	8	1	.	8	5	1	.	.	.	.	.	.	IY
LA	REL	11	1	.	8	5	1	.	.	.	.	.	.	B, P, M, V, F, W, R
LP	DENT	8	1	1	.	.	.	.	.	.	.	.	.	V, F
LP	PRO	12	1	1	.	.	.	.	.	.	.	.	.	AO, UW, UH, OW
LP	REL	9.11	1	1	.	.	.	.	.	.	.	.	.	V, F
TTCL	DENT	40	1	.	32	.	.	32	32	1	1	.	.	DH, TH
TTCL	ALV	56	1	.	32	.	.	32	32	1	1	.	.	D, T, N, Z, S, L
TTCL	ALVPAL	60	1	.	32	.	.	32	32	1	1	.	.	ZH, SH, JH, CH
TTCL	PAL	80	1	.	32	.	.	32	32	1	1	.	.	R, ER
TTCL	REL	24	1	.	32	.	.	32	32	1	1	.	.	D, T, N, DH, TH, Z, S, ZH, SH, JH, CH, L
TTCD	CLO	-2	100	.	32	.	.	32	32	1	1	.	.	D, T, N, JH, CH
TTCD	CRIT	1	10	.	32	.	.	32	32	1	1	.	.	DH, TH, Z, S, ZH, SH
TTCD	NAR	2	1	.	32	.	.	32	32	1	1	.	.	R, L, ER
TTCD	REL	11	1	.	32	.	.	32	32	1	1	.	.	D, T, N, DH, TH, Z, S, ZH, SH, JH, CH, L
TBCL	PAL	95	100	.	10	.	.	1	1	.	.	.	.	ZH, SH, JH, CH, Y, IY, IH, EY, EH
TBCL	VEL	100	10	.	10	.	.	1	1	.	.	.	.	G, K, NX, Z, S
TBCL	UVU	125	10	.	10	.	.	1	1	.	.	.	.	W, L, UW, UH, AH, AX
TBCL	UVUPHAR	150	1	.	1	.	.	1	1	.	.	.	.	OW
TBCL	PHAR	180	1	.	1	.	.	1	1	.	.	.	.	AE, AA, AO
TBCD	CLO	-2	100	.	10	.	.	1	1	.	.	.	.	G, K, NX,
TBCD	CRIT	1	100	.	10	.	.	1	1	.	.	.	.	
TBCD	NAR	2	100	.	10	.	.	1	1	.	.	.	.	ZH, SH, JH, CH, Y, W, L
TBCD	WIDE	10	10	.	10	.	.	1	1	.	.	.	.	Z, S
TBCD	REL	6	1	.	10	.	.	1	1	.	.	.	.	G, K, NX
TBCD	V	10	1	.	1	.	.	1	1	.	.	.	.	IY, IH, EY, EH, AE, AA, AO, UW, UH, OW, AH, AX
VEL	CLO	-0.1	0	.	.	.	.	.	.	.	.	1	.	B, P, D, T, G, K, V, F, DH, TH, Z, S, ZH, SH,
VEL	WIDE	0.2	0	.	.	.	.	.	.	.	.	1	.	M, N, NX
GLO	CLO	-0.5	100	.	.	.	.	.	.	.	.	.	1	Q
GLO	WIDE	0.4	0	.	.	.	.	.	.	.	.	.	1	P, T, K, F, TH, S, SH, CH, HH

Table I.4 Onset Exceptions

ARPA	C	TV	Constr
SP	P	GLO	WIDE
ST	T	GLO	WIDE
SK	K	GLO	WIDE
SF	F	GLO	WIDE

Table I.5 Coda Exceptions

ARPA	C	TV	Constr
W	W	TBCL	UVU
W	W	TBCD	NAR
R	R	LA	NAR
M	M	LA	REL
MB	B	LA	CLO
MP	P	LA	CLO
N	N	TTCL	REL
N	N	TTCD	REL
ND	D	TTCL	ALV
ND	D	TTCD	CLO
NT	T	TTCL	ALV
NT	T	TTCD	CLO
NX	NX	TBCD	REL
NXG	G	TBCL	VEL
NXG	G	TBCD	CLO
NXK	K	TBCL	VEL
NXK	K	TBCD	CLO
SP	P	GLO	WIDE
ST	T	GLO	WIDE
SK	K	GLO	WIDE
SF	F	GLO	WIDE
PS	P	GLO	WIDE
TS	T	GLO	WIDE
KS	K	GLO	WIDE
FS	F	GLO	WIDE

Table II.6 Mapping from syllable structure to coupling

```
% coupling.ph
%
% 2007/03/07 Hosung Nam
%
% standard phasing syntax file to generate ph.o file in gest.m

%%%%%%% oscillatory parameters and activation portion in cycle
v\d+ 3 1 4 1 NaN / 20 340 360           % vowel
v_rnd\d+ 3 1 4 1 NaN / 20 340 360       % rounding
ons\d*_CLO 6 2 4 1 NaN / 20 250 270     % CLO constriction
ons\d*_CRT 6 2 4 1 NaN / 20 250 270     % CRT constriction
ons\d*_NAR 6 2 4 1 NaN / 20 250 270     % NAR constriction
ons\d*_VOC 6 2 4 1 NaN / 20 250 270     % VOC constriction

cod\d*_CLO 6 2 4 1 NaN / 20 220 240     % CLO constriction
cod\d*_CRT 6 2 4 1 NaN / 20 220 240     % CRT constriction
cod\d*_NAR 6 2 4 1 NaN / 20 220 240     % NAR constriction
cod\d*_VOC 6 2 4 1 NaN / 20 220 240     % VOC constriction

ons\d*_h\d+ 6 2 4 1 NaN / 20 250 270    % glottal abduction
cod\d*_h\d+ 6 2 4 1 NaN / 20 220 240    % glottal abduction
ons\d*_n\d+$ 6 2 4 1 NaN / 20 250 270   % onset nasal
cod\d*_n\d+$ 6 2 4 1 NaN / 20 340 360   % coda nasal
DFLT 6 2 4 1 NaN / 20 160 180           % others


/coupling/

% C          = (clo | crt | nar | voc)
% CNS  = (clo | crt | nar)
% OBS  = (clo | crt)

% onset

% C-C coupling
ONS_OBS ONS_CNS 1 1 180    % anti-phase relation in onset clusters

% C-V coupling
ONS_CNS* V 1 1 0           % all CNS gestures synchronous with V
ONS_H V 1 1 0              % GLO synchronous with V, if not coupled to CNS

% within-C coupling
ONS_CNS ONS_REL 1 1 180    % REL is anti-phase with respect to Constriction
ONS_CRT ONS_H 1 1 0        % GLO gesture is synchronous with frics
ONS_CLO ONS_H 1 1 90       % else GLO gesture is delayed for stops
ONS_CLO ONS_N 1 1 0        % VEL gesture synchronous wih oral constr.
ONS_VOC ONS_NAR 1 1 0      % VOC gesture of /r/, /l/ sychronous with primary NAR constriction


% vowel
V_RND V 1 1 0              %rounding synchronous with V tongue constr.

% coda

% C-C coupling
COD_CNS COD_CNS 1 1 180    % C in coda are phased 180 degrees

% V-C coupling
V COD_CNS 1 1 180          % first coda CNS anti-phase to V
```

```
% within-C coupling
COD_CNS COD_REL 1 1 180    % REL is anti-phase with respect to Constriction
COD_CLO COD_H 1 1 90       % GLO gesture is delayed for stops
COD_CRT COD_H 1 1 0        % else GLO gesture is synchronous with frics
COD_N COD_CNS 1 1 180      % VEL gesture anti-phase to oral constr.
COD_VOC COD_NAR 1 1 180    % VOC gesture anti-phase to NAR constr.



/cross-syllable/
COD_CNS ONS_CNS 1 1 180          % applies if boundary is C$C
V ONS_CNS 1 1 180                % applies if boundary is V$C
COD_CNS V 1 1 0                  % applies if boundary is C$V
V V 1 1 360                      % applies if boundary is V$V

/cross-word/
COD_REL ONS_CNS 1 1 0            % applies if boundary is C#C
V ONS_CNS 1 1 180                % applies if boundary is V#C
COD_CNS V 1 1 0                  % applies if boundary is C#V
V V 1 1 360                      % applies if boundary is V#V
```