Appendix A: Model Implementation Details

Here, we present detailed descriptions of the network construction. The first step in constructing a given network involves specifying the type and high-level behavior of the neurons in the different layers, as well as specifying the set of grasps and objects that are to be encoded in the network. We first present the information that must be specified, and then show the number and distribution of neurons that are used in the experiments.

The second step in constructing a network makes use of the behavioral descriptions to heuristically generate the network wiring diagram.

Further details of this wiring process (including code), as well as access to the model itself can be found at http://www.usc.edu/dept/robotics/personal/af0a/thesis/

Network Structure Description

The behavioral descriptions of individual AIP and F5 units have already been presented in Chapter 5 (Tables 5.1 and 5.2, respectively). In addition we have discussed the representation of motor commands in MI (also Chapter 5).

The grasp description defines the configuration of the hand during and after execution of the grasp (Table A.1); this information is used to establish connections from F5 to MI to implement the movements during grasp execution. The *jacobian* and *expected tactile input* vector is used in selecting the MI cells that will be involved in responding to contact with the object. The *center position* is intended for use in the generation of arm movements (although this is not currently used in the model).

Variable	Description
Name	
Grasp class	One of *precision*, *power*, or *side*
Aperture	Final width (at time of contact)
Joint positions	For each joint, the position at which contact with the object is made.
Max aperture	For each joint, the position at which the maximum aperture is achieved during the preshape
Jacobian	For each joint, a measure of the derivative of the joint with respect to the aperture (at the point of contact)
Expected tactile input	A bit mask representing those tactile pads that will be active when a grasp is established.
Center	The T-matrix describing the transformation from the wrist to the center of the grasp. The orientation represents the opposition vector (between VF1 and VF2).

Table A.1: Description of grasp.

Variable	Description
Name	
Shape	One of *cylinder*, *sphere*, or *block*
Parameters	List of parameters and their corresponding values. Depending upon object shape, the parameters may include: *width*, *length*, and *depth*.

Table A.2: Description of objects.

The object description table describes the shape and size of each object that is to be presented to the model (Table A.2). This information is used in deriving the representation of objects in PIP and IT.

Finally, the object/grasp table lists for each object the set of grasps that are appropriate for the object. This table is used in establishing the set of affordances for each object.

Number and Distribution of Neurons

The number of neurons in each layer is presented in Table A.3. Due to computational limitations, the different experiments that are performed with the model rely on different network configurations. Although the classes of defined cells in AIP and F5 (grasp type, etc.) might change from one experiment to another (as do the affordance mappings from PIP to AIP), the ratios of basic cell types (e.g., in F5: set, extension, flexion, hold, release) remain essentially the same. In the bigger picture, we can imagine the network used for each experiment as being a component of a much larger network. The general robustness that has been observed in the model (with respect to numbers and types of cells) leads us to believe that the model will scale to this more general case.

Table A4 details the number and distribution of F5 and AIP neurons for two experiments described in Chapter 6.

Layer	Number of Units	Comments
PIP	183	
Object classes	3	cylinder, sphere, block
General shape neurons per class	1	
Neurons per parameter per class	30	
AIP	50 - 232	Number depends upon the number of grasps represented.
F5	213 - 750	Depends on number of grasps (type and aperture size) represented.
MI	480	divided evenly between position, force, and anti-force
SI	178	
Tactile cells	28	
Hand joints	15	
Proprioceptive neurons per joint	10	
SII	6 - 24	Depends on number of grasps (type and aperture size) represented.
BG	16	
Phasic	10	Two units for each motor program phase.
F5_Recurrent	1	Inhibitory feedback.
BG_Recurrent	1	Inhibitory
Grasp_Bias	4	
F2	4	One for each grasp that can be associated with an arbitrary stimulus.
F6	5	Four units for task-based selection of grasp type; one for general priming of the grasping program.
Area 46	213 - 750	Depends on number of F5 units.

Table A.3: Number of cells in each model layer.

Description	1 object/2grasps: Prediction #2	Size Variation: Prediction #4
F5 Cells	430	750
AIP Cells	110	232
F5 Cell Grasp Orientation		
Precision Pinch	242	750
Lateral Pinch (side opposition)	188	-
F5 Cell Parameter Coding		
General (no specificity)	170	82
Aperture	260	668
F5 Cell Phasic Responses		
set	56	100
extension	197	278
flexion	202	286
hold	65	139
release	50	115
AIP Parameter Coding		
General (no specificity)	51	24
Aperture	59	208
AIP Grasp Orientation		
Precision Pinch	63	232
Lateral Pinch	47	-
AIP Phasic Responses		
set	46	98
extension (early)	46	98
flexion (late)	18	36
AIP V/M Orientation		
Pure Visual	11	19
Visual Dominant (V>M)	49	135
Motor Dominant (V<M)	30	49
Pure Motor	20	29

Table A.4: Distribution of F5 and AIP cells for two experiments (Predictions #2 and #4 of Chapter 6).

Network Wiring Rules

The following define the heuristic network wiring rules. Although the network is programmed using information from discrete tables (finite number of objects, grasps, and sizes), because the network makes use of a population encoding scheme to represent objects and grasps, a reasonable degree of generalization is achieved. Thus, rather than a discrete set of objects and grasps, the system is capable of representing entire classes.

PIP -> AIP

For each affordance/AIP unit pair (set-related units only):

If the grasp type of the AIP unit matches the affordance grasp type:

If the AIP unit does not encode aperture:

With a given probability, associate the representation of the object in PIP to this AIP unit (connection is made to the signal input of the AIP column).

The strength of the connections is proportional to the AIP cell's *visual* response, and a random value (selected from a uniform distribution). So cells with a zero visual response will not receive PIP inputs.

Otherwise if the AIP unit aperture matches the object width* (or other parameter encoding the object dimension along the opposition vector):

With a given probability, associate the PIP representation of the object parameter to the AIP unit (connection is made to the signal input).

The strength of connection is proportional to the AIP cell's *visual* response, the degree of match* between the object width and AIP aperture, and a random value (selected from a uniform distribution).

*Match is related to the difference between object width and grasp aperture. Degree of match is gauss(width-aperture, *std*), where std is a parameter that determines the sensitivity to the difference.

IT -> AIP

For each affordance/AIP unit pair (set-related units only):

If the object is "known" by the model and the grasp type of the AIP unit matches the affordance grasp type:

If the AIP unit aperture matches the object width (or other parameter encoding the object dimension along the opposition vector):

With a given probability, associate the IT representation of the object parameter to the AIP unit (connection is made to the signal input).

The strength of connection is proportional to the AIP cell's *visual* response, the degree of match between the object width and AIP aperture, and a random value (selected from a uniform distribution).

AIP -> AIP

Four possible conditions: S->S, S->G, G->S, and G->G (where S=specific - i.e. parameters, G=general - no parameters).

For each pair of AIP units:

If the AIP units match in grasp type and in aperture size (latter applies only to S->S):

With a given probability, a connection is established from one column to the support input of the other column. The probability is a function of the condition.

The strength of connection is proportional to a constant that is a function of the condition, a random value, and the degree of match between the two apertures (S->S case).

AIP -> F5

Two conditions: S->S and G->G

For each AIP/F5 pair that falls into one of the two conditions:

If the grasp type matches:

If G->G case:

With a given probability, a supporting connection is established from the AIP cell to the F5 cell.

The strength of connection is proportional to a random value.

If S->S case and the apertures match:

With a given probability, a supporting connection is established from the AIP cell to the F5 cell.

The strength of connection is proportional to a random value, and to the degree of match between the two.

F5 -> AIP

Two conditions: S->S and G->G

For each F5/AIP pair that falls into one of the two conditions:

If the grasp type matches and the phases match[*]:

If G->G case:

With a given probability, a signal connection is established from the F5 cell to the AIP cell.

The strength of connection is proportional to a random value.

If S->S case and the apertures match:

With a given probability, a signal connection is established from the F5 cell to the AIP cell.

The strength of connection is proportional to a random value, and to the degree of match between the two.

* If the AIP cell is a set onset cell, then all phases match. If the onset is early, then no connections are established from F5 set cells; if the onset is late then no connections are established from F5 set or extension cells.

F5 -> F5

Four possible conditions: S->S, S->G, G->S, and G->G (where S=specific, G=general).

For each pair of F5 units:

If the F5 units match in grasp type and in aperture size (latter applies only to S->S):

With a given probability, a connection is established from one column to the support input of the other column. The probability is a function of the condition.

The strength of connection is proportional to a constant that is a function of the condition, a random value, and the degree of match between the two apertures (S->S case).

F5 -> Mcx

For each F5 unit that specifies an aperture:

Compute the goal joint positions for this cell (taking into account responsiveness to tactile inputs)[*]. These goals are a function of the type of grasp that the cell codes and its phase.

Randomly select a subset of joints to drive.

Recruit a set of Mcx cells that achieve the goal positions for the selected joints. This computation is performed using a pseudo-inverse with corrections to remove negative weights.

*The goal positions recruited by and F5 unit depends on the phase during which the cell responds (see Chapter 5):

Set phase: no connections

Extension phase: Mcx position cells are recruited that achieve the maximum aperture.

Flexion phase: Mcx position cells are recruited that achieve the expected object width. Mcx inverse-force cells are recruited in anticipation of contacting the object.

Hold phase: Mcx position units maintain the approximate finger positions, force and inverse-force cells are recruited such that a specific force is maintained.

Release phase: Mcx position and force cells are recruited that cause the fingers to open beyond the size of the object.

F5 -> SII

For each grasp program (grasp type and aperture) that is specified by the grasp description table, three SII cells are allocated (which detect maximum aperture, object contact, and object release).

F5 aperture-specific cells provide positive priming connections to the corresponding SII units:

extension-related cells in F5 prime maximum aperture detectors.

flexion-related cells in F5 prime contact detectors.

release-related cells prime SII release detectors

SII -> F5

Maximum aperture detectors provide signal inputs to F5 flexion units.

Contact detectors provide signal inputs to F5 hold units.

Release detectors inhibit F5 release units and cause the grasping program to shut down.

SI -> SII

Maximum aperture detectors receive proprioceptive information for all joints that correspond to the maximum aperture specified by the corresponding grasp table element.

Contact detectors receive both proprioceptive and tactile (force) inputs. The tactile inputs that are received correspond to those pad at which a tactile input is expected.

Release detectors receive inputs from force inputs.

SI -> Mcx

Discussed at the end of Chapter 5.

F5 <-> Area 46

Each unit in F5 is paired with a unit in area 46. During execution of a grasp in the light, the A46 unit remembers the highest value achieved by the F5 unit. This acts as a memory of the grasp that was executed. When a subsequent grasp is executed in the dark, the A46 unit provides positive support to the F5 unit that is proportional to the memorized activity level.

AIP <-> BG

Every AIP unit sends a positive connection to the BG_AIP_Recurrent unit. An inhibitory signal is returned to all AIP units.

F5 <-> BG

For the interaction between the F5 cells and the BG_F5_Recurrent unit, the interaction is the same as in AIP.

Also through the BG, it is possible to bias the selection of one of the grasp types. One of four BG units is allocated to each of the grasp types. Activation of one of these BG cells provides positive support to those F5 units that code the grasp (but do not encode a specific aperture).

F6 -> F5/AIP

The F6 unit responsible for detecting the context of the experiment primes all units in F5 and AIP.

F6/F2 -> BG

Task-related constraints (as represented in F6) and abstract stimuli (as detected by F2) can bias the grasp selection.

Protocols

Vanilla Protocol

The basic protocol (grasping in the light) proceeds as follows:

1. At the beginning of the trial, the object is presented by setting up the relevant representations in PIP and IT.
2. After a delay period, the *ready signal* is presented.
3. After another delay period, the *go signal* is given. The system responds by producing a preshape and a grasp.
4. After a hold period, the *secondary go signal* is given. The system responds by releasing the object.

Grasping in the Dark

1. Object is presented and grasped in the light, during which area 46 collects a representation of the F5 program.
2. Object representations in IT and PIP are cleared (turning out the lights). The memory in area 46 is imposed on F5. Protocol then proceeds the same as in steps 2-4 in the vanilla protocol.

Object Fixation

At the beginning of the trial, the object is presented by setting up the relevant representations in PIP and IT. No other stimuli are presented during the trial.

1 Object/2 Grasps (conditional case)

1. At the beginning of the trial, the object is presented by setting up the relevant representations in PIP and IT.
2. After a delay period, the *ready signal* is presented.
3. After a delay, the *instruction stimulus* is presented by setting up an activity pattern in F2.
4. After another delay period, the *go signal* is given. The system responds by producing a preshape and a grasp.
5. After a hold period, the *secondary go signal* is given. The system responds by releasing the object.

1 Object/2 Grasps (non-conditional case)

1. At the beginning of the trial, the object is presented by setting up the relevant representations in PIP and IT. The pattern corresponding to the task-constraints is set in F6.
2. After a delay period, the *ready signal* is presented.
3. After another delay period, the *go signal* is given. The system responds by producing a preshape and a grasp.
4. After a hold period, the *secondary go signal* is given. The system responds by releasing the object.