

## NEURO-11: A computer system for relating neural spike trains to physiological and behavioral data

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NEURO-11 is a data acquisition, storage, retrieval, and analysis system for investigating the relationship between single-unit activity and behavior. Although other systems have been developed for the evaluation of neural data (Wyss & Handwerker, 1971; Roemer, Cegavske, Thompson, & Patterson, 1975), this system has unique capabilities for long-term acquisition over many data channels and subsequent analysis using a high-level computer language. The experiments for which NEURO-11 was designed examine the relationship of cerebellar neuronal firing patterns to several behavioral and physiological measures in the unanesthetized cat.

At the outset of an experiment, one does not know the exact nature of the relationship between the activity of a neuron and sensori-motor events. The computer system presented here makes use of peri-event histograms and raster displays to uncover these relationships. These displays are constructed relative to a stimulus or motor reference point called a node. A node can be almost any event that is recorded simultaneously with the neuronal activity; for example, the increase of electromyographic activity (EMG) in a particular muscle, the placement of a limb in a predetermined location, or the presentation of a sensory stimulus. A peri-event histogram is constructed by choosing a node and examining the neuronal firing pattern forward and/or backward in time. Typically, the raster display and the associated cumulative histogram is generated by choosing a number of samples. Within a given data set there can be

many different nodes. NEURO-11 allows the investigator to select nodes one at a time within the same data set and to test hypotheses about the relationships between nodes and neural data.

**System prerequisites.** This system is designed for a PDP-11 with 24K core storage, an RK-05 removal disk cartridge, and a Laboratory Peripheral System (LPS). The required LPS subsystems are the eight-channel analog-to-digital converter (A/D), the programmable clock, and the 16-bit digital I/O option. Other hardware includes a Tektronix 4010 graphics display terminal as the console device and a simple latch interface for the LPS digital input register. The latch interface stores digital data arriving on 16 digital input lines until the computer can read it. NEURO-11 runs under DEC DOS/BATCH-11 (V9-20C) using the MACRO-11 assembler and FORTRAN compiler.

**Input program (ALLIN).** The system consists of two programs: a data input program (ALLIN) written in assembly language and an interactive data retrieval, manipulation, and display program (ANA) written primarily in FORTRAN. The input program, ALLIN, was designed to efficiently encode and store a high volume of input data for a sustained period. The primary inputs are pulse (event) data occurring on the digital input lines. These digital events are the occurrences of neural spikes and stimulus or motor event markers. Analog voltages can be recorded on all or any combination of the eight A/D channels. The output of the program is a disk file which contains encoded input and control data. This file is later read and decoded by the analysis program (ANA). Data are organized into sessions which are partitioned into trials by means of a switch connected to one of the digital input lines. The disk address of each trial is stored in a trial directory so that any trial within a session is rapidly accessible.

**Data representation.** The input program (ALLIN) generates four different types of data words: clock, digital event, A/D, and time code words. Each type of data word is distinguishable by the value of its high-order 2 bits. The format of these words is shown in Figure 1. A clock word is generated and stored on the disk every 500 msec. The low-order 14 bits of this word

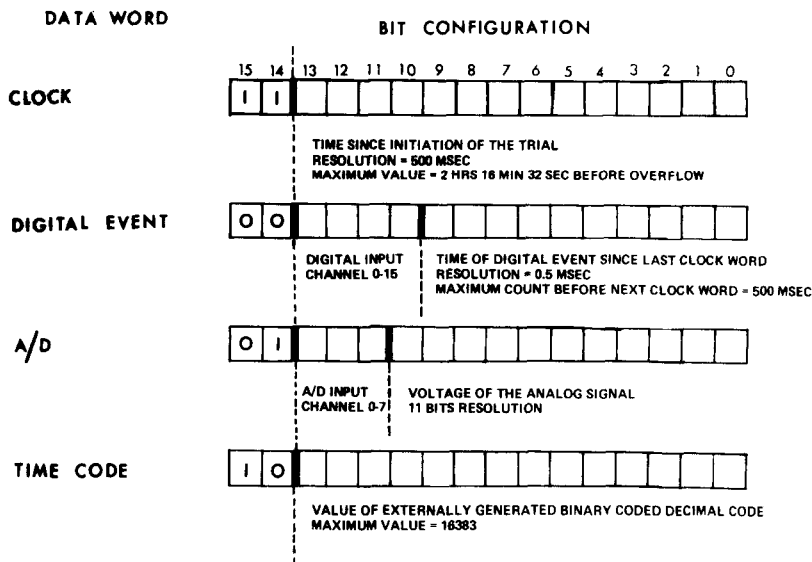


Figure 1. Bit configurations for the four types of data words used by NEURO-11.

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hold the time count (in 500-msec steps) since the beginning of the trial. If an input occurs on a digital line, a digital event word is generated and stored. Four bits of this word identify the input channel, and the low-order 10 bits indicate the time (in .5-msec steps) since the last clock word. An A/D data word is generated

for each A/D conversion. Three bits specify which channel was sampled and the A/D value is placed in low-order 11 bits of this word. Since A/D conversion occurs at a fixed rate, the time of occurrence of any A/D conversion is easily computed. The fourth type of data word is the time code word that is used to synchronize computer data with on-line analog tape and chart recordings. An external code generator produces binary coded decimal time codes that are converted to a binary format and placed in the low-order 14 bits of the time code word.

**Input program organization.** The input program ALLIN consists of four major routines: initialization, foreground data sampling, background data storage, and program termination. The initialization routine locates the last session on the disk file, adds the new session identification label, sets up the A/D parameters, and determines the disk address where new data are added. The foreground routine, which is executed every .5 msec, reads the digital input lines, increments the time, and samples the A/D channels. This routine also stores digital event, A/D, clock, and trial termination data in a core memory buffer. The background routine transfers these data to the disk, monitors the console terminal, and maintains the trial directory. The termination routine insures that all data in the buffer are transferred to the disk and that all files are properly closed. The input program can accommodate 51 separate sessions per data disk, and a total of 2,047 trials. It can also handle a sustained data input rate of 2,000 A/D samples/sec and more than 2,000 digital events/sec. Each clock word, digital event, and A/D requires one word of disk storage.

**Analysis program (ANA).** The analysis program (ANA) is an interactive data retrieval, manipulation, and display program. Since this program was intended to undergo frequent revision, it is designed as a collection of utility routines written primarily in FORTRAN. All of these are FORTRAN callable subroutines which may also be executed directly from the console terminal using keyboard commands. Several examples of these commands are given in Table 1. Upon entering the program, the operator specifies the session and trial in which the data are to be analyzed. Data within the trial are selected for analysis with respect to some node. The three operational modes available for the selection of nodes are scan, search, and preprogrammed mode. Scan mode (SC command, Table 1) is used to sequentially display raw data on the terminal. All digital event channels, A/D channels, and the time codes for a given data segment are displayed simultaneously. The length of the displayed data segment is specified by the operator and can range from 500 msec to several minutes. Any point in the data can be specified as a node by the use of a vertical cursor on the terminal. Data segments from A/D and digital channels are extracted and stored on separate disk files for subsequent display and analysis. Figure 2 illustrates the data extraction in scan mode. The cursor (Figure 2A) is positioned at the beginning of a period of integrated EMG activity in the triceps muscle. In this example, data from all channels were taken for a period 400 msec before to 600 msec after the cursor position or nodal point. Figure 2B shows the extracted data segment. Data segments can be collected in scan mode until 100 temporary data storage files are filled.

In search mode (SR command, Table 1), an imaginary pointer may be placed anywhere in a trial. A search forward or back (in time) from the pointer can be conducted for a digital event, an A/D conversion, clock word, or time code. Thus, one can skip quickly to specific locations in a trial without scanning the raw data sequentially. At any time, the pointer can be used as a node, so that a segment of either A/D or digital event data may be extracted and placed in a temporary storage file on the disk for subsequent analysis.

The third mode of data selection, the preprogrammed request, is used when the experimental paradigm is more formalized. Using the preprogrammed mode involves writing a series of FORTRAN subroutine calls on the available utility routines.

**Table 1**  
Summary of Interactive Keyboard Commands for the  
Data Analysis Program ANA

Command	Title	Operation
DD	DATA DIRECTORY	Lists all session descriptions and their session numbers.
GS	GET SESSION	Allows user to specify the session to be analyzed.
GT	GET TRIAL	Allows user to specify the trial (within a session) to be analyzed.
RS	RESET	Resets the pointer to the beginning of current trial.
SR	SEARCH	Initiates a search forward or backward for an A/D or event on a channel or for a specified clock word or time code. All searches proceed from current location of the pointer.
LO	LOCATION	Prints the session number, trial number, and current location of the pointer.
TC	TIME CODE	Prints the first and last time codes associated with the current trial.
KI	KILL	Terminates program ANA.
BF	BUFFER	Extracts a specified data segment from the raw data and places it in the temporary buffer.
II	INTEREVENT INTERVAL	Computes an interevent interval frequency distribution and places it in the temporary buffer.
SC	SCAN	Displays successive data segments. During the scan, the BF and II functions can be performed using a terminal cursor to define data segments.
FI	INSPECT FILES	Lists data file descriptions and summary data.
SV	SAVE BUFFER	Saves the temporary buffer as a data file.
RC	RECALL BUFFER	Recalls a data file to the temporary buffer.
CL	CLEAR FILE	Clears (deletes) a specified data file.
AD	ADD FILES	Adds the contents of two or more data files, yielding a summed data file. Also subtracts when data file number is preceded by a negative sign.
DS	DISPLAY FILES	Displays data files on the display terminal.
CH	CHANGE HEIGHT	Allows user to change the height scale of a histogram display.
CB	CHANGE BIN	Allows user to change the bin size of a histogram display.

If, for example, an experimental paradigm requires a 750-msec segment of data to be collected before and after an event on digital channel 2, this request can be satisfied by a routine consisting of a few FORTRAN subroutine calls. Furthermore, this routine can be given a two-character request code, so that it may be called from the terminal keyboard when needed. Figure 3 shows the firing pattern of a cerebellar neuron (Channel 1) with respect to the placement of the right (Channel 2) and left (Channel 3) paw during a cat's normal walking pattern. A short

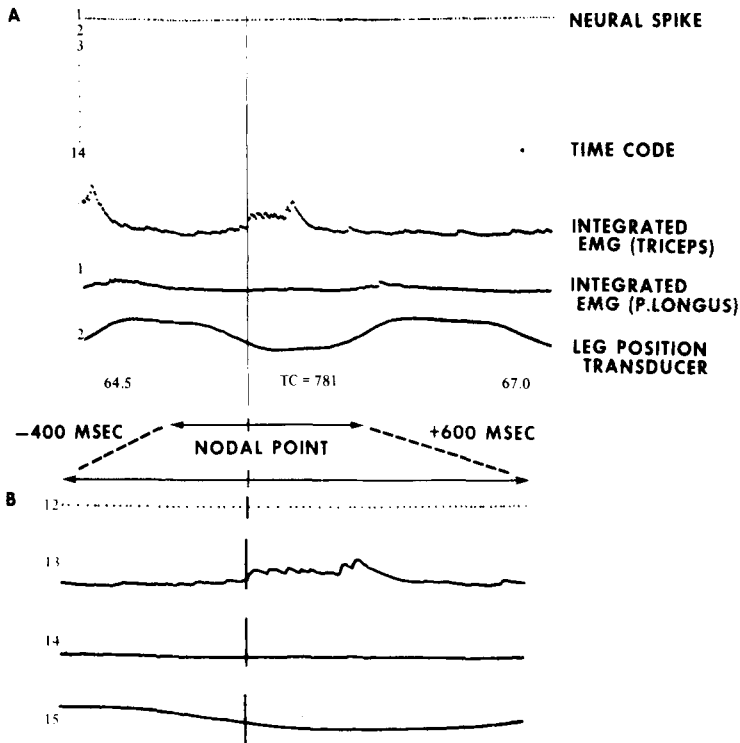


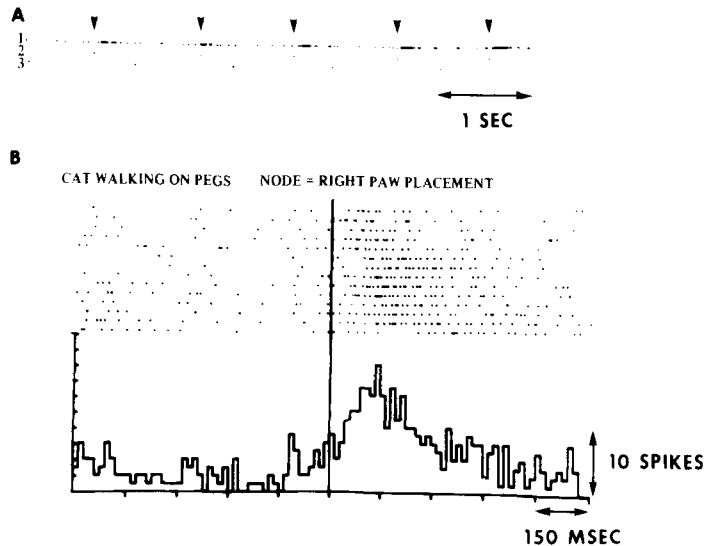
Figure 2. A 2.5-sec display of a neural spike firing pattern, integrated EMG activity, and limb position data (A). The dot on Channel 14 indicates the occurrence of a time code (TC = 781). The two numbers (64.5 and 67.0) at the bottom show the start and finish time of the display (relative to the beginning of the trial). A vertical cursor positioned at the increase of integrated EMG activity (triceps muscle) defines a nodal point. Preselected data segments (B) are extracted for a period of 400 msec before and 600 msec after this nodal point.

FORTRAN routine (Figure 3C) directs the computer to use the right paw placement as a node and to extract neuronal spike data for a period 750 msec before and after this node. The resulting raster display and associated cumulative histogram for 14 such nodal points is shown in Figure 3B.

**Data manipulation and display.** Each extracted data segment is stored in a temporary disk file. There can be up to 100 data storage files and these can be easily created, stored, combined, displayed, and deleted. Files may be combined with files of the

same format using the AD command (see Table 1). For example, if several event files are extracted using the same stimulus node, a peri-stimulus histogram of event frequencies can be formed by combining the files. A/D files containing evoked response signals collected for the same node can be combined to form averaged evoked responses. Files may be displayed by typing the DS command (Table 1). The program automatically displays as many files as can fit on the display terminal and waits for a continue command before presenting a new display.

Figure 3. Example of the use of a pre-programmed request to extract neuronal spike data for one node: (A) a 5-sec segment of cerebellar neuronal activity associated with right (Channel 2) and left (Channel 3) paw placement; and (B) the raster and cumulative histogram formed when right paw placement is used as the node. Vertical arrows in A indicate the nodal points. Data were extracted for a period 750 msec before and 750 msec after each nodal point. This operation was performed for 14 nodal points using the FORTRAN statements in C.



```

C
DO 100 I=1,14
CALL SEARCH (I,2,K)
CALL BUFFER (I,1,-0.75,0.75,0)
100 CALL SAVBUF (I)
    
```

**Advantages.** The computer system presented here facilitates the operation of discovering relationships between neural spike trains and physiological or behavioral variables. A node in a particular variable can be chosen and changes in spike firing patterns noted. Subsequent comparisons can be made by picking additional nodes and repeating the process. In addition, one can select any node either manually by visual inspection of the data (scan mode) or automatically by means of a simple FORTRAN program (preprogrammed mode).

A second advantage of the system is that multiple comparisons between all of the recorded variables can be made for the same node. During an experiment, one typically records several variables along with the neural spike train. Often the investigator is not able to follow concomitant changes in the other variables. NEURO-11 permits one to make multiple comparisons between several channels of digital (neural spike, stimulus, or motor events) and analog (behavioral-physiological) data.

**Availability.** Listings are available from the authors without charge. Copies of the programs may be obtained for the cost of duplication and mailing. The address is Department of Pharmacology, Temple Medical School, 3420 North Broad Street, Philadelphia, Pennsylvania 19140.

#### REFERENCES

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