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MASSACHUSETTS INSTITUTE OF TECHNOLOGY CAMBRIDGE, MASS. 02139

from the office of

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TO: Morton Berlan
R. G. Mills
W. Burner
T. Van Vleck
F. J. Corbató

FROM: J. H. Saltzer

SUBJECT: Dataswitch Primer

Enclosed is a draft of a memo describing how the M.I.T. Dataswitch operates, from the point of view of the computer owner who wants to interface to it. Your comments as to its

. accuracy

. readability

. Usefulness

. completeness

are welcomed.

DRAFT II
8/18/69

A PRIMER ON THE M.I.T. DATASWITCH

by J. H. Saltzer, M. I. T. Project MAC

This memo gives a brief introduction to the operation of the telephone switching equipment used for data-terminal to computer interconnection at M.I.T. It is directed primarily at persons responsible for operation of computers with remote (terminal) access capabilities, since intelligent operation and planning frequently requires some understanding of the limitations of the particular switching equipment used.

The Dataswitch, as it is known, is a Bell System model 711 step-by-step private branch exchange which is supplied and maintained by the New England Telephone Company. It consists mostly of racks of "stepping switches", which are basically electrically operated relays which allow connection of a single telephone line to any of the 100 (or sometimes 200) other lines. The M.I.T. configuration is described in table I.

The overall view of the Dataswitch is that two kinds of telephone lines converge on it; its function is to make appropriate interconnections among the lines as requested by persons dialing.

How the DataSwitch Works

Lines which are assigned 4-digit numbers are known as loops. Loops are usually used for typewriter consoles and are capable of either originating or receiving calls.

The loop consists of a pair of wires, named tip and ring, across which the telephone transmitter and receiver are placed (thus completing the loop and giving the name) or data signals are transmitted. Where the loop enters the dataswitch, a third wire, the supervisory or sleeve* lead, accompanies the circuit to carry control signals. All connections within the exchange are then 3-wire connections. For example, when a phone is taken off hook, the change of resistance upon closing the loop is detected by a relay at the exchange which grounds the sleeve lead accompanying the circuit.

A special kind of line which can only receive calls is known as an auxiliary trunk; auxiliary trunks are usually attached to computer ports, and have auxiliary trunk numbers which are related in groups to the single-digit numbers dialed to call them.

It is necessary to trace a call through the exchange in order to understand some of the exchange's limitations. When a loop is taken off-hook in preparation for making a call, a stepping switch known as a line finder goes into action, searching for the line which went off-hook. When it finds the grounded sleeve lead, it stops there, thereby completing a three-wire connection between that line and a second stepping switch, known as a first selector, which is paired with that line finder. When this connection is complete, a dial tone is heard.

The caller now dials his first digit. The dial sends out DC pulses corresponding to the digit dialed, across the tip and ring leads. The successive dial pulses cause the selector to climb up to one of the ten levels. When the correct level is reached, the selector then scans across the ten lines

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* On a manual switchboard, the three wires go to the tip, center, and sleeve of the operator's phone plugs, the center wire being the one connected to the source of bell ringing current when necessary; thus the names.

on that level looking for one that is not busy. If one is found, the selector stops and the originating loop is now connected to that line. If calling a computer with a single digit number, the line connected to is one of the auxiliary trunks leading to a computer port. If calling a 4-digit number (another loop) the line connected to goes on to a second selector switch which will accept the second digit and repeat the process. In both cases, it is possible that all ten outgoing lines on the level were busy (a line is busy if another line-finder/selector pair has previously connected to it; this condition is detected by noticing that the sleeve lead is grounded) in which case a busy signal will be heard by the caller.

We have so far introduced enough ideas to discuss grading. If a computer has, say, 50 ports, there will be 50 auxiliary trunks from the Dataswitch to the computer. From the above discussion it should be clear that any one person who picks up his phone and dials a one-digit computer number will only scan some set of 10 of the 50 auxiliary trunks, and will get a busy signal if all of that set of ten happen to be busy, even if some of the 40 remaining suxiliary trunks are not busy. To help minimize the probability of such occurrences, different line-finder/selector pairs are connected to scan different groups of ten lines, and in different orders. In response to observed frequent busy signals from some line-finder/selector pairs, it is possible to rewire them to search over auxiliary trunks which are observed to be more lightly used. This rewiring is known as grading. In order to measure frequency of busy signals, one particular computer trunk, with a counter attached, is placed as the tenth line on every selector.

A fundamental limitation of this arrangement of switching equipment now becomes apparent: If 49 of the computer ports are in use, a potential 50th user has only a 1 in 5 chance of getting the unused port; 4 times out of 5 he will get a busy signal. In other words, one cannot expect in practice to be able to make use of all auxiliary trunks simultaneously; one must have some number of spares in reserve. For example, a 50 user time-sharing system might have to be prepared to accept calls on 60 trunks in order to keep busy signals acceptably rare while approaching the 50 user [illegible] limit.* Note also that if one decides to temporarily throttle down to, say, 15 users on the above system, the time-sharing system must still be prepared to accept calls on all of its 60 trunks, since one cannot predict which trunks will be drawn by the 15 users who are allowed to log in.

The discussion above has concentrated on connections between loops and single-digit computer numbers. It is also worthwhile to explore inter-connections between two loops, requiring that a 4-digit number be dialed. As mentioned above, dialing the first digit results in a hunt for a free second selector. There must be a pool of second selectors with some excess in it, just as there needed to be an oversize pool of auxiliary trunks before. Dialing the second digit causes the second selector to climb to an appropriate level, and hunt for an unbusy line (hunting over ten again) and connect to it. Since after dialing two digits, the field of choice is now narrowed down to 100 possible telephone numbers, the line coming out of the second selector

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* If one presumes calls to originate at random with respect to the grading pattern, then it is quite easy to compute the maximum allowable loading of the trunks for a given probability of a busy signal. The following table indicates some sample values for 30 or more trunks:

probability of busy signal	allowable loading of trunks
.01	70%
.05	85%
.1	90%

A tendency to allocate telephone numbers to contiguous offices in blocks makes the randomness assumption a bit artificial, but the above loading figures suggest the order of magnitude of the problem.

runs to a connector, a third type of specialized stepping switch which has each of the 100 possible telephone numbers attached to its 100 positions. The third and fourth dialed digits then move the connector to the correct level and position in that level respectively and the connection is completed; or a busy signal is returned, depending on the status of the sleeve lead of the particular loop which was called.

This latter connection strategy, while simple, has the implication that each group of 100 contiguous telephone numbers must have some number of connectors (say 12) dedicated to it; that number (12) represents the maximum number of simultaneous conversations which can terminate on those 100 lines. In particular, if a computer port is assigned to a 4 digit (loop) number rather than a one digit (auxiliary trunk) number, it must be presumed that one connector in that 100 line group is dedicated to serving that computer port. If insufficient connectors are provided, or they are incorrectly graded, busy signals at the second selector will prevent use of that computer port.

In the discussion above, no mention was made of allocation of line-finders. Each block of 200 contiguous loop numbers has assigned to it a set of line-finder/selector pairs, connected in a chain. When any of the 200 loops goes off hook, the first free line-finder in the chain begins scanning over its 200 switch points looking for the off-hook loop. If another loop goes off hook, the next line finder in the chain is automatically triggered. The chain of line finders is connected in a ring, and different loops actually trigger the line-finder chain at different but fixed starting points. This technique is intended to equalize the load on the line-finders and thus the outgoing trunks, but it has an ill side effect. Data holding times are very long and all of the line-finders, selectors, and connectors involved in a call are tied up for the duration of the call. To provide adequate service, there must be a large number of line finders. As a result, any individual loop tends to always get the same line-finder/selector pair and thus always search over the same group of 10 auxiliary trunks when dialing a single digit computer number. [A more elaborate version of the line-finder arrangement not used by M.I.T. because it takes up so much space, permits a "daisy-chain" arrangement in which each time a loop goes off hook it gets the next line-finder in the chain. Thus if a busy is encountered, by hanging up and redialing, one would be guaranteed to get a different line-finder/selector pair with a different grading, and thus a new chance to locate a non-busy auxiliary trunk.]

The 103E rack mounted dataset

This dataset is designed to be used for a computer port and intended to be connected to an auxiliary trunk, although it can be used for other purposes and in other configurations. It is connected to an auxiliary trunk by a three wire circuit, thus extending the supervisory (sleeve) lead from the dataswitch into the computer room. This lead is used to implement the "make busy" option of the 103E cabinet. If one wishes to make some line busy, because of a bad computer port or a bad dataset, it is done by grounding the sleeve lead. There are three observations to be made about this organization.

- If the sleeve lead is grounded by the 103E make busy function while a call is in progress, when the caller hangs up his ungrounding of the sleeve lead (which is the signal for all the switches to drop back to their inactive state) will have no effect, and the circuit will be hold until the 103E make busy function is released. While this feature is sometimes handy in tracing calls, it should be recognized as a potential trap also, since the caller's telephone would be rendered unusable.

- If a 103E dataset is attached to a 4-digit (loop) number instead of an auxiliary trunk, the make busy function cannot be implemented since the data switch does not provide a sleeve lead attachment point for loops. Taking the dataset "off-hook" will accomplish the same effect in principle, although it ties up a line-finder/selector pair as long as it is offhook.
- As mentioned earlier, certain auxiliary trunks have counters attached to them to measure busy signal frequency. Grounding of the sleeve lead on these trunks interferes with the operation of the counters so the make busy function can not be permitted to operate on them.

Further grading considerations

It is possible, by using more switchgear, to push the solution to the trunk loading problem mentioned above back into the exchange. One could, for example, use 2-digit numbers for access to computer trunks, and give the caller a choice of, say fi 2-digit numbers, each of which is guaranteed to hunt across a different group of 10 trunks, thereby giving him a methodical way of trying all 50 of the computer trunks. If this strategy is chosen, two consequences result:

- Each "conversation" between a user and a computer port now ties up a line finder and two selectors, 50% more switchgear than with single-digit numbers.

- In order to assure that a busy signal is not encountered after dialing the <u>first</u> digit, there must be an excess of properly graded second selectors.*

In principle, one would expect extra selectors (~$2/month) to be substantially cheaper than extra datasets and computer ports (~$150/mo[illegible] 360/67 and GE-645), and this approach to the problem should be much more [illegible]cal. Unfortunately, the current data switch at M.I.T. is severely limited in physical space, and this consideration frequently becomes the controlling one.

<u>Debugging, Troubles, etc.</u>

A few general comments about how one diagnoses difficulties encounted in using the data switch are in order.

- If busy signals are encountered frequently on single digit computer numbers despite observed loading below that indicated in the footnote of page 4, it is probably an indication that regrading can help. Information consisting of the caller's telephone number and the list of trunks observed not in use at the time the busy signal was encountered, is the most useful input to the regrading process.
- If the dataswitch appears to make an incorrect connection, or a dataset does not answer a handshake properly, an appropriate way to proceed is to:

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* Loading of the second selectors obeys the same formulas as loading of computer trunks, so the excess of second selectors required is also given by the footnote on page 4.

1. Leave the telephone originating the call off hook. This will hold the switches in position.
2. Have the call traced at the Dataswitch. Tracing is done by examining the linefinders and selectors to see what position they are in.
3. Once the offending piece of equipment is found it can be made busy (by grounding its sleeve lead) until repaired. This applies inside the Dataswitch as well as to a particular data set.

A very useful debugging tool is a patchboard in the computer room which allows connection of any auxiliary trunk, and some 4-digit loops, to any dataset. When trouble is suspected in a particular dataset or computer port, by connecting it to a 4-digit loop one has a simple way to be sure that he can dial to the dataset in question. In addition, if busy signals are encountered with a light trunk load, the 4-digit loops can be patched into service to provide access until regrading is accomplished. These extra access paths are also valuable on weekends or evenings, when a busy signal, bad circuit, or bad dataset is encountered in dialing via the usual path and tracing help is not available.

<u>M.I.T. Data Switch Configuration</u>

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<u>Loop numbers</u>

1100–1200	60 line finders/1st selectors	12 connectors 12 connectors	50 2nd selectors (all 5 groups of 12 connectors)
1300–1400	60 line finders/1st selectors	12 connectors 12 connectors	
1500–1600	60 line finders/1st selectors	12 connectors	
1700–1800	not in use		
1900–1000	not in use		

level numbers

2 not in use

3 not in use

4 20 auxiliary trunks to 360/65 (planned to replace loop numbers)

5 29 auxiliary trunks to 360/67 (planned to replace loop numbers)

6 12 trunks to Lincoln Lab, Bell Telephone labs, and MIT PBX

7 14 auxiliary trunks to 645/Multics

8 32 auxiliary trunks to 645/Multics

9 8 auxiliary trunks to 7094 CTSS

0 32 auxiliary trunks to 7094 CTSS

Calls originating from MIT PBX, Lincoln Lab, or Bell Labs share the line finder/1st selectors of the 1500-1600 loop numbers.