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Analytical-Plotter, IBM-360/50 Interface System

Time sharing with a large off-line digital computer offers advantages in flexibility.

INTRODUCTION

At the 1968 International Congress of Photogrammetry we presented a paper which reported on the plans of the University of New Brunswick to interface the O.M.I.-Bendix Analytical Plotter of the type AP-2C with the general purpose Computer IBM 360/50.[1]

Since then the interfacing has been completed and it is the purpose of this paper to describe its functioning and its use. The reasons for undertaking the project lie in the possibility of experimenting with an analytical plotter system with a third-generation computer which has vastly improved characteristics over the presently available analytical plotter computer models. Table 1 compares these characteristics for the AP/C computer and the computer model IBM 360/50 H of the University of New Brunswick.

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TABLE 1. COMPARISON OF AP/C COMPUTER WITH IBM 360-50H

	AP/C	*360-50H*
Type	serial, binary	hexadecimal with decimal and floating pt. hardware
Word length	28 bit incl. parity	32 bit
Period	9.3 μ sec	0.5 μ sec
Storage	delay lines	core
Capacity	3584 words	64000 words
Extensive storage	—	58 million words (disk, tape)
Storage cycle	9.3 μ sec to 2.6 m sec	2 μ sec
Speed	3 million bits/sec	16 million bits/sec 312 K bytes/sec disk 60 K bytes/sec tape
Data input	60 chars/sec paper tape	1000 cards/min
Data output	10 chars/sec hard copy or paper tape	300 cards/min card punch 1100 lines/min printer

The advantages of the IBM 360/50 computer are obvious:

- The computing speed is considerably higher, and therefore real time requirements, which are imposing severe limitations in the AP/C computer, are considerably relaxed when using the 360.
- The internal computing storage of the 360 is up to 17 times larger, and it is random access.
- External storage facilities of the 360 of million words on disk, as well as storage on tape, offer practically unlimited opportunities to collect data and to store programs ready for direct access.
- The data input and output speed of the 360 is several magnitudes higher than that of the AP/C.
- The programming capability of the 360 is by far superior: the 360 possesses a multiprogramming system, powerful compilers such as Fortran IV and PL/1, and a versatile assembler. Opposed to that the AP/C ordinarily only permits fixed-point machine language programming, which is particularly difficult

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due to the 1½ address structure, the large number of instructions (up to 64), and the program time optimization requirement due to use of time-dependent delay line storage.

The largest deterrent to integrating a computer of the 360/50 capabilities with an analytical plotter system is of course the computing cost. However time-sharing operation offers new and interesting possibilities to keep costs very reasonable. This is particularly true if the analytical plotting system is supported by a small on-line computer for the real time calculations; this occurs for the interfaced system AP/C-360/50.

ABSTRACT: *The analytical plotter may have gained a new dimension through the time-sharing concept. Interfacing the AP/C with the IBM 360/50 has been a fortunate venture because extensive use could be made of existing IBM software, and because programming the system is relatively easy. Even if the model 50 computer is replaced with a model 65 at a later date, software conversion will be minimal because the 1827 process controller will remain as an input device for further IBM systems. The interfacing can therefore be viewed not only as a means to expand the capability and research potential of the plotter, but also as a step to include software considerations as an important component in the future development of analytical plotters. No doubt the analytical plotter will have a future in both respects if it can be utilized on a time-shared basis with standard up-to-date digital computers.*

In particular, the system permits one to study photogrammetric problems of increased complexity, and as such it becomes a future-oriented tool for experimentation.

SYSTEMS DESCRIPTION

THE AP/C COMPUTER

The function and the organization of the AP/C computer of the University of New Brunswick is summarized in Figures 1 and 2.

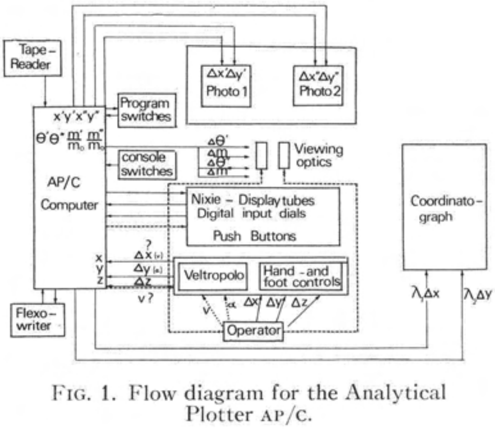

FIG. 1. Flow diagram for the Analytical Plotter AP/C.

Outside of its main function to convert model coordinates into image coordinates, it services the input and output devices (flexowriter, tape reader), the Nixie displays, and it interrogates program switches, dials and push buttons; the University of New Brunswick AP/C computer also permits one to alter viewing direction and magnification of the viewer optics, similar to the AS-11-A computer.

These functions are executed with one instruction register, three arithmetic registers, a short-delay line serving as a multiple word register, 14 delay lines of 256 words of 28 bits each, internal and external circuits, as well as three buffers used for real-time input/output, for general input/output, and for viewing-optics outputs.

THE IBM 360/50H

The 360/50 installation of the University of New Brunswick is schematically described in Figure 3. Utilizing this computer installation without hardware modifications real-

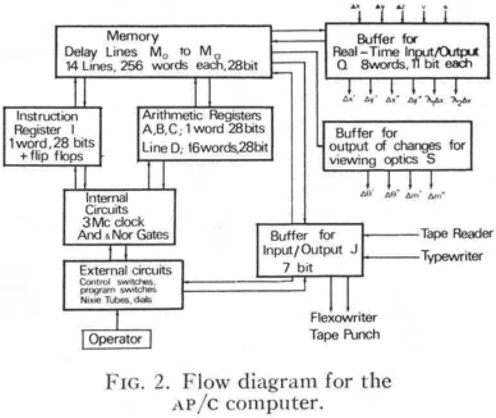

FIG. 2. Flow diagram for the AP/C computer.

time input/output of 16 bit signals is possible through the 1827 Process Controller which constitutes an integral part of the 360 system.

THE AP/C-360 LINK

In order to interface the AP/C and the 360–50 computers, a hardware link had to be built for a two-way transfer of words between the AP/C registers *A*, *B*, *C* and *DO* to *D15*, and the 16 inputs and outputs of the 1827 Process Controller of the 360. The hardware consists of two 28-bit buffers, 5 flip-flops, and the associated control circuitry built with Texas Instruments Integrated Circuits. In addition, a number of new AP/C instructions had to be wired in order to operate and test the link The hardware is described in Figure 4.[2]

As the AP/C computer is physically located one floor above the 1827, not farther than a total distance of 100 feet apart, the link hardware could be incorporated into the AP/C computer; it was connected with the 1827 by a 36-line coaxial cable.

OPERATION OF THE LINK

For the operation of the link, both computers (the AP/C and the 360) must be in a ready state and programmed in succession.

Transfer of data from AP/C to 360. For the transfer of data from the AP/C to the 360 the following steps need to be programmed:

AP/C Program

1. A new AP/C order tests for input ready-sync signals of the 360. If these are present, the 1827 is in an input-wait state, otherwise testing is repeated indefinitely.
2. The AP/C output flip-flops are initialized to zero to indicate beginning of the transfer.
3. Using a new AP/C order, the contents of one of the 28-bit registers *A*, *B*, *C* or *DO* to *D15* are read into the AP/C output buffer *LO*.

Hardware

4. Hardware transfers the first 14 bits of *LO* plus the bits of the flip flops marked *format*

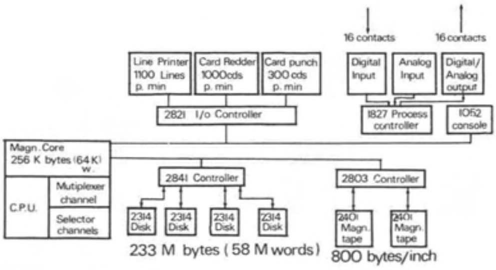

FIG. 3. Flow diagram for the IBM 350/50H of the University of New Brunswick.

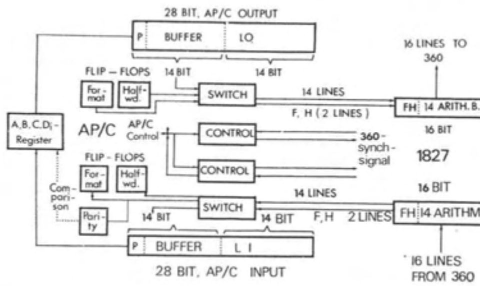

FIG. 4. Flow diagram for the AP/C-360 link.

and *half-word* (=0) to the 1827, and after that sets the half-word flip-flop equal to 1.

360-Program

5. The 1827 passes the received 16 bits into the 360 core and stores them there.

Hardware

6. A new sync pulse from the 360 initiates the transfer of the second half of the *LO* buffer, and after transfer sets the half word flip flop equal to 0.

360-Program

7. The 360 stores the second half of the word into core. Parity is checked by counting the transferred bits. If parity does not check an appropriate signal is sent to the link and retransmission of the word is initiated. If parity checks, a sync pulse returns control to the AP/C and steps 1 to 7 are repeated to transmit further words until a last word AP/C order is given, setting the format flip-flop to 1. This will terminate the transfer.

Transfer of data from 350 to AP/C. For the transfer of data in the reverse direction the following steps are accomplished.

360-program

1. A 360-program sends the first half of a 32-bit word to the 1827 in succession until transmission is completed.

AP/C program

2. A new AP/C order tests for output ready sync pulses of the 360.

Hardware

3. If a sync pulse is received the first 16 bits of the 32-bit 360 word are transferred into flip-flops and buffer *LI*.

360-program

4. The 360 then sends the second half-word.

Hardware

5. The second half-word is again transferred into flip flops and buffer *LI*. The parity flip flop is set according to bit 28 which contains parity in the 360 core in coded form.

AP/C program

6. Control is returned to the AP/C, which reads *LI* by a new order into one of the registers *A*, *B*, *C* or *DO* to *D15*.

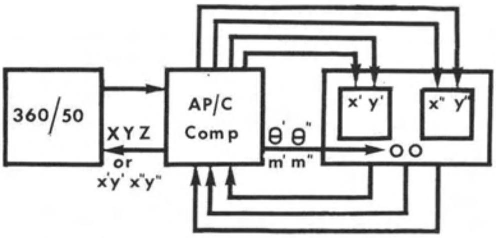

FIG. 5. Program and data transfer. Off-line—program library, intermediate data. On-line—tabular corrections to image or model coordinates, or to orientation parameters.

7. Thereafter parity is computed and checked with that contained in the parity flip-flop. If it is incorrect, a coded word is sent to the 360 and retransmission of the last word occurs. Otherwise the sequence of steps 1 to 7 is repeated for the next word.

The long sequence of steps needed for the link operation might give the impression that the data transfer is a lengthy procedure. This is not the case. In fact the entire AP/C memory of 3584 words can be transferred to the 360, or vice versa, in 3 seconds.

PROGRAMMING FOR LINK-OPERATION

Programs for link operation were written in assembler language; for the 360 two macros were written in 360 assembler to transfer a word from the 360 core to the 1827 and vice versa. For the AP/C programs a specially written AP/C assembler was used. This AP/C assembler, written in PL1 compiler language by a member of the University of New Brunswick Computing Centre staff, permits one to assemble time-optimized AP/C programs using the 360. The input consists of mnemonic operator codes and labelled addresses on punch cards. Output in this instance is a typewriter code listing printed on the line-printer of the 360, which can be used for punching on the AP/C teletype flexowriter for preparation of the AP/C program tape.

SYSTEM USES

USE FOR PROGRAM AND DATA STORAGE

The simplest use of the system is for intermediate program and data storage utilizing the 2314 disk facilities of the 360. For this use the 360 programming can be kept to a minimum because it is only necessary to transfer and to store AP/C words in coded form as they come into core from the 1827. They can be used in this form for retransfer into the AP/C without modifications (Figure 5).

To facilitate this type of use, a 360-program (*CREAT*) has been written, which creates a program library on a 2314 disk owned by the Department of Surveying Engineering. Three versions of this program exist; in each instance a library member, which can be up to 3584 words long (the full AP/C memory), may be created using a name consisting of four alphanumeric characters.

The first version permits to dump the whole AP/C memory onto a labelled disk location in about five seconds. The second version permits to load an AP/C program tape which is read into the AP/C computer directly onto disk into a labelled location. The third version creates the member directly from the AP/C assembler which is being compiled on the 360.

Another program (*FETCH*) was written to recall a desired library member specified on the AP/C teletype into AP/C memory.

The creation and use of the program and data library has the following advantages:

* The lengthy paper-tape loadlng of programs, which may take up almost 10 minutes for loading the entire AP/C memory, can be avoided by program-loading from disk within a few seconds.
* Computer shutdown, incorporating the data of the latest orientation step performed is easily accomplished by dumping the whole AP/C memory onto disk.
* One of the weaknesses of the present AP/C real-time program is the possibility of destroying orientation or the program by incorrect operator action. Here the operator presently sometimes has to reload the program and in particular has to repeat all orientation steps. The new memory dump procedure into the 360 is so quick that a transfer of the whole memory after each orientation step is not time consuming to influence operating time and therefore advisable in the event something unforseen happens. A recall of memory will then not only recover the program, but the orientation as well.

For the three mentioned advantages, real-time operation is not necessary, and wait-states of a few seconds before the operation can be carried out in multiprogramming mode, are not critical. Another use of a program and data library is possible in real-time operation and is contemplated for the future; the present time-dependent delay line memory does not make it possible to use table-lookup for the correction of image coordinates, model coordinates or orientation parameters. As of now, corrections can only be programmed for real-time use, if they can be expressed as analytical functions. But it is primarily the use of table lookup which offers new possibilities for the following applications:

¶ Evaluation of reseau photography and of transmitted or TV-photography carrying reseaus.

¶ Use of a self calibrating program to improve AP/C spindle accuracy on the basis of grid-measurements.

¶ The formulation of non-classical imagery evaluations is possible by precalculating corrections which will transform the imagery to a standard photography case which can be treated by the real-time program for ordinary photography. Such corrections may be stored by table-lookup. It is conceivable that panoramic photography, X-ray photography and images of other sensors may be evaluated in this fashion.

¶ If the non-classical imagery is time-dependent (continuous strip photography, scan imagery of the radar, infrared or ultraviolet type) then further table storage of the orientation parameters ω, ϕ, κ, X_0, Y_0 and Z_0 as a function of time, and thus of the image coordinates, becomes possible.

The attractive feature of the table-lookup approach is that all corrections may be precomputed from calibration data on a general purpose computer using Fortran programming. The Analytical Plotter System in turn only needs one table-lookup program to accommodate all possible cases. To enter table lookup data into the AP/C, and further on disk, only a list of constants needs to be punched on the teletype and fed into the computer via paper tape.

USE FOR DATA OUTPUT

A more sophisticated way of using the system is for data output via the 360. This is described in Figure 6. In general the output will be through the on-line printer of the 360-system. To utilize the transferred AP/C information, decoding into a bit configuration compatible with the IBM 360 word structure must be accomplished. The decoding is different depending on whether the transferred information refers to AP/C instructions or AP/C constants.

In printing AP/C instructions, the operation code bits, the operand and the next instruction address code bits are extracted into separate fixed-point 360 words and printed out in succession. A program has been written in conjunction with the described AP/C memory dump routine to print out a listing of the transmitted memory portion after the transfer has taken place. Such a listing is the best aid in debugging AP/C machine-language programs.

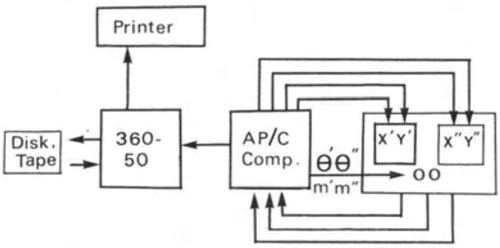

FIG. 6. Data output. Off-line—coordinates of points, orientation parameters (triangulator). On-line—digital terrain model.

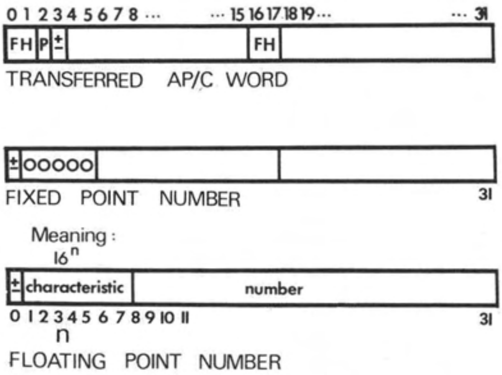

FIG. 7. Transformation of AP/C words for use as data in the IBM 360–50.

If the transfer refers to AP/C constants, then a conversion into a 360 fixed-point number or a 360 floating-point number can be executed. This is illustrated in Figure 7. Where one is converting the AP/C word into a fixed-point number, the 4-format and half-word bits (0, 1, 16 and 17) should be discarded. The sign bit (3) is shifted three bits left. The number portion of the left half of the AP/C word (bits 4 to 15) is shifted two bits to the right. The right half of the word (bits 18 to 31) is copied. The remaining four bits (1 to 5) of the 32-bit 360-word are padded with zeroes. The scaling of the word is then identical to that in the AP/C before transmission.

Converting a word into a floating-point number requires a further routine which places the most significant bit of the number into bit 8, and which determines a suitable characteristic (bits 1 to 7), depending on the predetermined scaling of the AP/C word and the left or right shift required to bring the most significant bit into position 8. The characteristic n in the 360 has the significance of 16 to the power n.

In transferring coordinate values from the AP/C, further rescaling is necessary due to the fact that the AP/C handles coordinates internally as 2-μm increments with the decimal point shifted left by 2 bits. Rescaling to μm-values in the 360 therefore required a division by 2^3, or 8.

For this mode of operation a program was

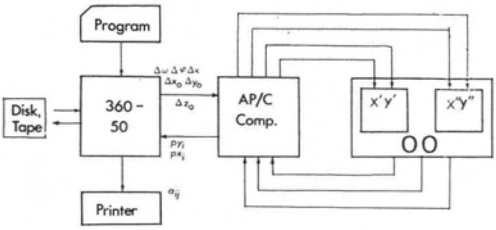

FIG. 8. For use as a two-way data transfer. Off-line application of subroutines written for the 360, e.g., relative orientation, combined interior-relative-absolute orientation.

written[3,4], which stores a complete digital terrain model in form of successive x, y, z coordinates onto magnetic disk. Although the AP/C is programmed to scan the stereomodel in profile mode and while the operator controls the z-variation, the digital terrain model is dumped automatically at specified model coordinate increments. During the scan the 360 is operated in multiprogramming mode with high priority for servicing the link. In order to enable a fast transfer of coordinates x, y and z, parity checking is replaced by a more efficient sum-check method which first forms the coordinate sum in the AP/C, then transmits it and compares it with the computed sum in the 360.

It is significant that the stored digital terrain-model record can be addressed by Fortran IV programs of the 360. In particular it becomes possible to use it with existing programs such as those available for the design of highways in the I.B.M.-Massachusetts of Technology *ICES* package, or those for deriving contour information for graphic output via the Calcomp plotter.

Further uses of the link for data output are envisaged in the following manner. The Analytical Plotter may be utilized as an efficient triangulator for aerial triangulation. After the orientation of a model the constants, the orientation matrices, and subsequently the coordinates of the transfer and control points, may be transferred onto disk together with their coded model and point numbers. These data can be made directly addressable by a Fortran programmed independent-model block-adjustment program on the 360.

USE FOR TWO-WAY DATA TRANSFER

A use of the system for two-way transfer of data, in which the data are transformed in the 360 by Fortran programs, also requires the decoding of data. Possible uses include the easy generation of sub-routines for which the following are examples (see Figure 8):

- A significant speed-up in orientation procedures becomes possible through modification of the relative orientation routine. This is very important if one considers that aerial triangulation can be performed presently on the AP/C at the rate of 25 minutes per model, but that almost 10 minutes of this time are spent on relative orientation computations. It is therefore desirable to dump the measured y- and x-parallax values, and the instantaneously computed coefficients of the observation equation matrix, into the 360 and to solve the least-squares problem there by a Fortran program. Consequently the data must be in 360 format. After completing calculations within a few seconds, control can be transferred to the AP/C. This procedure should make it possible to increase the efficiency of the AP/C as a triangulator by 65 percent.
- Following this line of thought it should be just as easy to write an AP/C orientation program which carries out the semi-automatic measuring part of a combined interior/relative/absolute orientation program. The measured data could be dumped and the orientation computed in the 360. The computed orientation parameters could then be returned to the AP/C.

USE FOR ASSEMBLER PROGRAMMING OF AP/C

The AP/C assembler written for the 360 system has already been mentioned.[5] According to Figure 9 it is possible to transmit the assembled AP/C instructions contained in the 360 in coded form of several fixed point words into the AP/C. Such a program has been written and it is now possible to program the AP/C via the 360 system. This offers considerable advantages in debugging.

REAL-TIME USE

The 360 link was built to permit real-time operation of the AP/C, using the 360 as a real-time computer. In this application, the AP/C merely acts as a buffer to service the encoders and the servo systems. All actual calculations are programmed on the 360 for the 360 (see Figure 10). The real time requirement can be satisfied if the two-way data transfer, including verification plus all calculations in the 360, can be executed in 33 m sec. Inasmuch as in

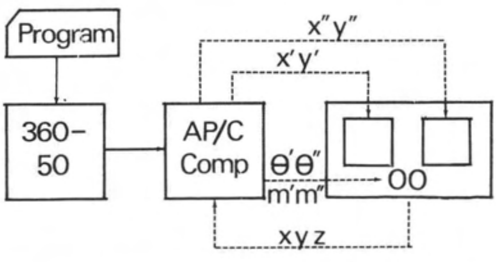

FIG. 9. Assembler programming of the AP/C through the IBM 360–50.

this way data transfer, plus verification for up to four words, can be accomplished in 7 m sec, the 360 may be used for the remaining 26 m sec for real-time calculations. This is sufficient for even the most complicated formulations.

It is obvious that this type of use is the most expensive with respect to 360 computer time but the least expensive with respect to software when new formulations are involved. So far real-time programming of the 360 to operate the link has not yet been undertaken, but it is planned in the near future (Figure 11).

USE AS AUTOMATIC COORDINATOGRAPH

Similar to real-time use, the 360 can be programmed to pass information only to the buffer portions of the AP/C coordinatograph outputs. In this way it becomes possible to utilize the AP/C coordinatograph as a precise automatic plotting device of the 360-50 at comparatively low cost.

With simple hardware modifications, an additional instruction may be generated in the AP/C computer to effect lifting or lowering of the stylus. This would widen the present capabilities of the coordinatograph as an automatic plotter. A more refined, but slightly more expensive modification, would include light-point drafting onto a sensitized emulsion.

A variety of uses in this mode is possible, including the output of contour lines computed from a digital terrain model.

CONCLUSIONS

Having reviewed the present and possible uses of the interfaced system, it becomes quite clear that the analytical plotter concept has gained a new dimension through the time-sharing concept. Interfacing the AP/C with the IBM 360-50 has been a fortunate venture

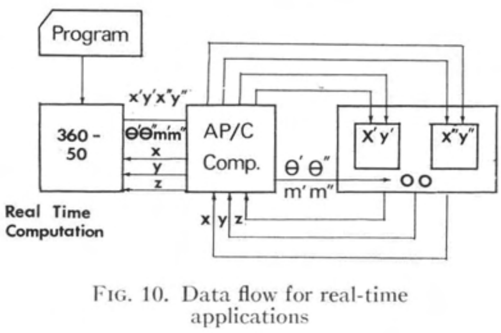

FIG. 10. Data flow for real-time applications

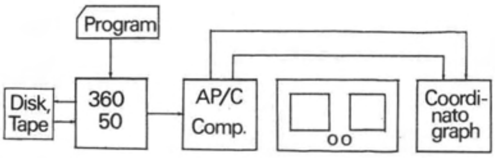

FIG. 11. Data flow for the application as an automatic coordinatograph.

because extensive use could be made of existing IBM software, and because programming the system is relatively easy. Even if the University decides to trade the present model 50 computer for an IBM 360 model 65 at a later date, software conversion will be minimal because the 1827 process controller will still remain as an input device for further IBM systems. The interfacing can therefore be viewed not only as a means to expand the capability and the research potential of the analytical plotter, but also as a step to include software considerations as an important component in the future development of analytical plotters. No doubt the analytical plotter will have a future in both respects if it can be utilized on a time-shared basis with standard up-to-date digital computers.

ACKNOWLEDGEMENTS

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