Automation in Optical Astrophysics

The Proceedings of Colloquium No. 11 of the
International Astronomical Union
at Edinburgh, 12 to 14 August, 1970

https://doi.org/10.1017/S0252921100032127 Published online by Cambridge University Press

est dès l'origine
ılement les gens
: autochthone et
dont il s'agit a
n'y est pas venu
ndigènes des An-
ıthones ni abo-
origène il n'y a
t purement éty-
l'esprit l'opinion
la terre, tandis
la question d'o-

ıme, et de χθὼν,

j. Marmite auto-
es aliments sans
. Même sens.
: qui se cloue,
ıu).
), *s. f.* Observa-
même qui l'é-

AUTOCRATRICE
ıveraine dont la
contrôle légal.
ous le nom d'au-
ent contempler
à Cath. 140. On
mpire de l'auto-
r le livre des dé-
l'honneur d'en-
olontés de cette
rgental, 10 nov.

, que l'usage du
as légitimement
oduit par αὐτο-

, même, et de
ıi-même.
. || 1° Gouverne-
es systèmes mé-
mpire qu'exerce
ours et la durée

), *adj.* Qui appar-
. Gouvernement

|| 1° Exécution,
par l'Inquisition

— ÉTYM. *Autographie.*

† **AUTOGRAPHIQUE** (ô-to-gra-fi-k'), *adj.* Qui a rapport à l'autographie.

AUTOMATE (ô-to-ma-t'), *s. m.* || 1° Machine et, en particulier, machine imitant les êtres animés, qui se meut par ressorts. Les automates de Vaucanson. || 2° Fig. Le sot est un automate, il est machine, LA BRUY. 11. Impuissantes machines, Automates pensants mus par des mains divines, VOLT. *Disc.* 2. Il vous faut désormais, si vous avez un roi, Automates tremblants sous sa main protectrice, Respirer ou mourir au gré de son caprice, M. J. CHÉN. *Timoléon*, II, 6. || 3° *Adj.* Le flûteur automate de Vaucanson. || Fig. Quelquefois le tyran automate [un pacha] se traîne à la porte de sa tanière, CHATEAUB. *Itin.* 258. Dans sa vie automate, l'habitude lui tient lieu de raison, J. J. ROUSS. *Ém.* II.

— HIST. XVI[e] s. Ilz bastissoient plusieurs petitz engins automates, c'est à dire soy mouvans euix mesmes, RAB. *Garg.* I, 24

— ÉTYM. Αὐτόματος, spontané, de αὐτὸς, même, et de μάτος, effort, de μάομαι, chercher, s'efforcer : celui ou ce qui fait effort par soi-même.

† **AUTOMATIE** (ô-to-ma-sie), *s. f.* Terme didactique. || 1° État d'un automate. || 2° Pouvoir de se mouvoir, d'agir spontanément.

— ÉTYM. *Automate.*

AUTOMATIQUE (ô-to-ma-ti-k'), *adj.* || 1° Terme de physiologie. Qui s'exécute sans la participation de la volonté. Le mouvement automatique du cœur. || 2° Terme de philosophie. Qui appartient à l'automatie ou spontanéité.

— ÉTYM. *Automate.*

† **AUTOMATIQUEMENT** (ô-to-ma-ti-ke-man), *adv.* À la manière d'un automate.

— ÉTYM. *Automatique*, et le suffixe *ment.*

† **AUTOMATISER** (ô-to-ma-ti-zé), *v. a.* Rendre automate. Vos règles vous ont fait de bois [vous ont ôté tout mouvement], et, à mesure qu'on les multiplie, on vous automatise, DIDER. *Lettre à Mme de Riccoboni.*

— ÉTYM. *Automate.*

† **AUTOMATISME** (ô-to-ma-ti-sm'), *s. m.* || 1° Terme de physiologie. Ensemble des mouvements non voulus ou des impulsions non voulues. Une grande partie de l'automatisme est, chez les animaux, sous la dépendance de la moelle épinière. || 2° Terme de philosophie. Faculté de se déterminer par soi-même. || 3° Dans le langage général, disposition qui fait qu'un homme n'est qu'un automate.

— ÉTYM. *Automatiser.*

† **AUTOMÉDON** (ô-to-mé-don), *s. m.* || 1° Dans l'Iliade, le conducteur du char d'Achille. || 2° Fig. et par plaisanterie, celui qui conduit une voiture.

tomne météo
vulgaire et qu
quinzaine de
l'automne du
feuilles, VOLT.
la vieillesse. Q
son hiver soit
|| 4° Dans l'alch
philosophique
— REM. Le
des règles entr
minin. Ils ont
l'adjectif préc
l'adjectif suit
cieuse; que c
et l'adjectif soi
tomne est du
ces distinction
tions. D'autre
genre et font
cun mal à c
puisque, par
condamner un
vains du XVII[e]
trait comme u
— HIST. XV
hons; Autres s
biens requeul
Poésies mss.
tomne est sec
ques fois l'aut
714.
— ÉTYM. P
otoño; portug.
ou plutôt *auctu*
augmenter, et
auctor, auteu
participe moye
mais dont on
dans *Vertumn*
dans *Pilumnu*
grec, et *man*
donc la saison
AUTONOMI
l'autonomie. ||
Quelques pens
lon et d'autres
Cartésiens avai
porains, se fra
Kant, p. 140.
— ÉTYM. A
μος, loi (voy.
AUTONOMI
les Romains a

https://doi.org/10.1017/S0252921100032127 Published online by Cambridge University Press

Introductory Address

J. RÖSCH

Pic du Midi and Toulouse Observatories

Automation is one of too many recently-coined words that have a magic power for those who value only novelty, whatever it conceals. Assuredly, the I.A.U. Executive Committee made no such hasty judgement when it placed its confidence in those of us who proposed a colloquium on automation; but it is our responsibility, now, to show that such a colloquium is justified—to show both that automation is necessary to the progress of astronomy, and also that the topic is worth a colloquium.

And first of all, what does *automation* signify? I trust that you will excuse my taking illustrations from the French language.

Littré's Dictionary (1873), the accepted reference work (that of the Académie Française has far too long a time-constant), does not mention it, but it is very instructive to read the related articles, and the following points are worth noting:

the basic French word is *automate*, from αὐτὸς, self, and μάτος, effort: to exert effort by itself; to convert an object into an *automate* is *automatiser*, in conformity with the best rules of construction, and the act of doing so, though not given by Littré, must be called *automatisation*, according to the same rules;

automation is thus essentially incorrect; it is the word that would be derived from the verb *automer* (j'autome, tu automes, il autome, nous automons, etc. . . .), which has no meaning; it has lost the second part of automate, the element *-mate* that implies effort, without which the first part loses all meaning.

It will be said that this is a shorter word—a weak argument, especially since the incorrect form is two-thirds as long as the correct form. It will be said that the word has become adopted—that is true, and I am no Don Quixote to tilt at windmills; nevertheless that adoption is very regrettable, as in may other cases, often arising, by the way, from the absorption of a Latin or Greek root into the English language. Another example is *digitization*, a word that will surely be used many times during this Colloquium. Probably because we first counted on our fingers, the English word *digit* has been taken over from Latin in a sense that in French we can more appropriately express as *chiffre*. In order to distinguish between the representation of a physical quantity, by means of another physical quantity varying simultaneously, and by means of a number, we have used the terms *analogue* and *digital*, where it would have been more correct to say *numerical*. Thus ignoring the origin of words, we are led to speak of *digital control of machine-tools*, that is, their control with the digits—or fingers—to signify that they are no longer controlled by . . . hand! In this case only, it is true, we have decided to speak of *numerical control*; but we should have excluded *digital* and its derivatives in every case. I believe that these errors are more serious than they might appear, because they convey a certain intellectual laziness, a renunciation of analysis, against which we must struggle: the power of analysis is one of the essential properties of the human spirit, and it is unpardonable not to exercise it. That is not to speak of the often catastrophic consequences of using words in an ill-defined sense, words which to each of us attaches his own meaning.

Let us return then, if not to automation, at least to the automat.

What are the advantages of an automat generally, and particularly in astronomy? In answering this question we shall come to know the meaning and value of the problems to be considered during this colloquium, and we shall recognize the gaps that still remain and the ways that are to be pursued.

Without over-elaboration, we may list the following possible functions of an automat:

to make a mechanical effort in order to economize human effort:
to perform some discrimination in order to economize human sensory (usually visual) activity;
to perform some operation with more precision than an unaided human being:
to work faster than a human being.

There is a great philosophical difference between tasks that a man can perform without an automat, those for which an automat is indispensable, and those that only a man, not an automat, can perform.

https://doi.org/10.1017/S0252921100032127 Published online by Cambridge University Press

Thus, the use of motors permitting rapid movements can (in principle) be avoided by making several men work together if one alone should not be strong enough. This method was employed by the Pharaohs to build the Pyramids, with no automation. Similarly, if an observer's eyesight becomes fatigued too quickly and he becomes incapable of performing his task correctly, then he can be replaced by another as frequently as necessary. Similarly again, if an operator takes one year to measure all the stars on a photographic plate, then a sufficient number of operators can be employed to ensure that all the plates taken in one year can be measured by the end of the year.

In all these cases, the automat yields a considerable practical advantage, because it multiplies the capabilities of a man and avoids the necessity to multiply the number of men employed.

The situation is quite different when there is a *threshold*, and one can set out to obtain *new* results, which could not be obtained by employing any number of men.

A typical example arose a few years ago in a developing country, which ascertained that the cost of a proposed highly automated astronomical instrument represented, taking into account local salaries, the remuneration of a group large enough easily to carry out the same work daily during twenty years. Some time later, the same country applied the same reasoning to a machine for manufacturing electron tubes; but in the latter case it was pointed out that no group, however large, and no individual, however skilful, could insert the lead-throughs into the glass during the very short period when it was just at the requisite degree of softness.

It is precisely the case that thresholds exist in human sensory mechanisms (we do not speak of muscular mechanisms, since they can be supplemented by automats of the first category). Two types of threshold concern us here: the energy threshold of retinal sensitivity, taking into account its integration time, and also the response times (chronaxies) of the various nerve circuits that intervene between sensory excitation and the motor activity that should result. The retina has high quantum efficiency (a few photons can be perceived), but an integration time of not less than a few tenths of a second. We can change nothing here, and our only remedy is to employ a more favourable detector: the photographic plate already yields an enormous gain, in spite of its very poor quantum efficiency, because it permits an integration time almost infinitely longer than the retina; and with photoelectric detectors we retain the advantage of integration while approaching the quantum efficiency of the retina. Furthermore, detectors other than the eye have the enormous practical merit of retaining a material record of the signal, in the form of a photographic image, a graphical registration, or otherwise. We then come up against another problem, the exploitation of all the information recorded; but this is a problem of the first type, which can be solved in principle by employing a large number of men.

The other type of threshold is the response time of the sensory and motor systems in a human being. This is not fundamental so long as one is not faced with very rapid phenomena. For example, in the case of measuring the coordinates of photographic stellar images, it results in a limitation in the number of stars measured in a given time; but this difficulty can be circumvented by employing many men instead of one, without any automat.

There are few phenomena, in astronomy, on a time-scale shorter than that of human reactions. But they do exist, and they are important. The most spectacular are the pulsars, which could never have been discovered by the human eye. A much more commonplace example is the diurnal motion of the stars. Long before the word automation was invented, astronomers had devised an automat to assist them in following this motion precisely; in driving their equatorial mountings by means of clockwork, they had achieved automation without knowing it, as Monsieur Jourdain, Molière's *Bourgeois Gentilhomme*, created prose.

They also perfected their automats, in order to obtain higher precision, by devising impersonal micrometers, where the observer's role is simply to maintain coincidence. It remains only to replace the eye by a photoelectric detector and we have a complete automat; but the essential goal, the elimination of the response time, was achieved long ago.

I ought not to be speaking about these astrometric devices, since the Executive Committee specified that this Colloquium should be devoted to "Automation in Optical Astrophysics"; but, I believe, that was only to guard against overloading, and I am certain that no-one will reproach us for considering the problems in their most general aspect.

Besides, even if astrometrists study or utilize diurnal motion, astrophysicists are subject to it also, and must take account of it in designing their apparatus.

Diurnal notion leads me to speak of a third case of phenomena too rapid for the human eye—those produced in the Earth's atmosphere. It soon becomes clear that a simple uniform movement leaves residuals. Some of these obey laws known in advance, and can be well corrected; this is the case for refraction, mechanical deformation of the instrument, and so on. It is sufficient to make the automat a little more complicated, to give it a "program", which it will faithfully obey. But this is not all; relative to its theoretical position, the image of a star will move in a rapid, random fashion, and furthermore it will never contract to the ideal diffraction pattern, but at each instant will be more or less irregularly spread out. And these effects, at a given moment, will depend on the aperture of the telescope.

We should ask, having explored the subject so far, whether it is worth the trouble to take account of these effects due to the atmosphere, and to seek to avoid them by means of automats. That they do constitute a limitation on the collection of astronomical information is certain. The blurring and motion of stellar images impairs the study of fine structure in extended objects, increases the probable error of the absolute or relative positions of stars (especially the components of binaries), reduces the efficiency of slit spectrographs, decreases the limiting magnitude (photoelectric or photographic) by reducing the concentration of energy, and so on. Some will doubtless reply that orbital telescopes will soon radically resolve these problems. This is possible, but surely not in the very near future. The most elaborate project we know is the "Skylab" recently announced by NASA. In his account of the scientific aims, Henry J. Smith speaks explicitly of the possibility of going from the 5 arcsec achieved by spacecraft like OSO or AOSO, to 1 arcsec, thanks to the presence of astronomers.

Now these plans are for the end of the 70s; whereas, from the Earth's surface, resolutions of 0.2 arcsec have been attained, and we hope occasionally to attain 0.1 arcsec within a few years. The next stage is a diffraction-limited three-metre orbiting telescope, doubtless for the early 80s, followed still later by the installation of a large telescope on the Moon. In view of this timetable, it is our duty to try to work as well as possible and as much as possible through the atmosphere, and, since the phenomena concerned are too rapid for the human nervous system, to see how automats may assist us.

The problem can be divided into two parts, considering both that the image of a point source is more or less deformed, and also that the centroid of the image patch is more or less displaced. The second aspect is the easier to tackle, and constitutes an extension of the guiding problem, which has already been dealt with in various ways: it is sufficient, for example, to control a relative displacement of the image and the detector by means of a beam-divider that splits the energy in the stellar image into equal parts. The first aspect is however much more subtle.

If the image is deformed, this is on account of path differences between the various rays in their passage through the atmosphere. To recover the theoretical structure of the image, it would be necessary first to know the values of these path differences at every instant, and then to correct the image appropriately. There exist solutions that do not have recourse to automats, pursuing the problem statistically to various stages; then the time factor is eliminated, but at the cost of a certain loss of information. If we wish to deal with the problem in real time (and various devices have been suggested in principle), we run into great practical difficulties. We can be less ambitious, and, instead of compensating image defects, attempt only to select instants when the images are least deformed; for this, automats have been not only proposed, but indeed constructed. Nevertheless, much more remains to be done.

The fact is that devices for guiding, selection, or compensation encounter limitations inherent in the nature of the phenomena involved. The first concerns the linear scale of the atmospheric inhomogeneities (of the order of 10 cm) compared with the height of the whole atmosphere (of the order of 10 km). The ratio of these quantities determines the maximum angular separation between points in the sky for which the atmospheric deformation is practically the same: observations show in fact that this is of the order of a few tens of seconds of arc. In other words, any attempt at guiding, selection, or compensation, if it is to be effective, can apply only to a very restricted field on the sky; and the idea of "instants of good seeing" implies also "for the point considered and its immediate neighbourhood". The second restriction, severe enough by itself, is aggravated by the first. To control an automat, it is necessary to separate off a certain fraction of the incident energy (and that from the same objective, or the deformation will be different), in order to analyse the information distorted by the atmosphere and deduce an "error signal". Since the time-scale is short, only a very brief integration is possible; and because the field over which this information is valid is very small, we are reduced, in practice, to feeding the control system to the detriment of the image itself, for which there is never too much energy available . . .

These difficulties prevent such methods from supplying a universal solution. But there are cases where they are justified and applicable, and here they constitute a branch of automation in astronomy so important and effective that it truly extends into the domain of that which neither one man nor a group of men could achieve.

I shall now examine the program of this Colloquium in the light of the foregoing considerations, trying to classify the contributions according to the types of automatic function that they concern.

Forty contributions are announced (not including this introduction and the final summary). Of these, six concern various special problems; seven discuss computers associated with telescopes or photometers; seven titles explicitly mention "automation of telescopes", and I presume that, as in the preceding contributions, there must be a question of making the use of the instrument and series of observations more rapid. I hope also, but am not sure, that they will mention problems of guiding, which actually appear only in two other titles. Finally, the remaining 18 contributions, or almost half, concern the utilization of photographic plates—star-fields, spectra, microdensitometry. Thus, almost all of the contributions concern what I shall call "multiplicative automats", those which multiply the power and speed of human actions, as distinct from "subliminal automats", those which do what a man cannot do on account of his physiological time-constants, and which are very little represented here. There is nothing surprising about that.

The former class are in fact combinations of components that do not differ fundamentally from those that can be used in any field other than astronomy. These components—computers, servo-mechanisms—have been widely developed by others. It is natural that astronomers try to take advantage of them, and that industry is interested in their efforts, because a new clientele is thereby created (on condition that astronomers can convince their masters that the development of astronomy must be accelerated, and that this implies much greater financial expenditure; for here too "time is money", not in the sense that to gain time is to gain money, but that money is needed in order to gain time).

The second class are—or will be—much closer to laboratory instruments, constructed in very small numbers, each adapted to a particular problem, and based on astronomical knowledge of their parameters. There was little to be said about them, at this moment, but I trust that in a few years they will have received sufficient development to justify a second Colloquium, in which they will play the major role.

It remains for me to speak of the third case enumerated earlier: that which only a man, and not an automat, can perform.

We have the habit of saying that an automat (and in particular a computer) is perfectly obedient and perfectly stupid. More precisely, an automat will do everything for which it was conceived, and nothing else; a man has conceived that goal, and it has no other. It will make all the choices that it is asked to make, but it is a man who defines the criteria of choice. It will search for whatever it is asked to search, on condition that a man has told it in advance the characteristics that are to be sought. It will assist a man, who has an idea, to discover something; but it will discover nothing itself.

What does it lack, and why is a man superior at this stage? It is because the human brain conceals much richer associative mechanisms than the simple electrical connexions that, for example, change the representation of a digit from 0 to 1 in a binary system. We may here and now suggest that the excitation of a neuron in the central nervous system is not localized at the extremity of one of its terminations, but "spreads" in the surrounding medium. Compared with the structure of a computer, it is equivalent to a transition from N possibilities to N^3, a gain of two orders of infinity. And perhaps the selectivity of its modes of action generates one or more further infinities. Perhaps, even, connexions in the brain are made in the equivalent of a "function space".

There results, for the brain, a prodigious aptitude for integrating information—and this is with time-constants much shorter than when motor reactions are involved. This integration permits, on the one hand, the operation of genuine special "senses" impossible to express in machine language—any more than one could express the meaning of taste or smell—and on the other hand, comprehension, in the etymological sense of "bringing together". I trust I may be permitted to quote two examples in fields that I know well — (that is just why I have chosen them).

Consider first the stereoscopic sense. The brain compares the right and left retinal images of an object, and the differences of perspective cause it to reconstruct the location of the object in space. We can, in the reverse sense, transform slight deformations of a two-dimensional image into an effect of depth, and thus attach to each point of a field a third dimension that can be related to a certain parameter. In this non-codeable "sense of relief", human eyes can be used in some cases to replace an automat. Thus, in a recent article describing the GALAXY machine, P. FELLGETT points out that its extensive use could have led to the discovery of quasars (we repeat, moreover, that it is not the machine that would have discovered them, but the astronomer who would have had the idea of using it to search for exceptionally blue stars). But suppose we form a stereoscopic pair with two photographs of a star-field taken through an objective prism of very weak dispersion, in opposite directions for each. Then blue stars, at a glance and before any measurement, will appear "in front of" red stars (or vice verso). This stereoscopic technique, without any automat, could have been used to discover the quasars, too.

But still more important, and above all more general, is comprehension. It is this combination of apparently distinct elements that, thanks to the brain, leads to the discovery of a new element; this is

https://doi.org/10.1017/S0252921100032127 Published online by Cambridge University Press

what an automat will never do, for there is nothing new for it, only what has been built into it from the outset. Here I shall give my second example. Images of photospheric granulation have been produced; they have been analyzed in the microdensitometer, and their autocorrelations have been studied, in one dimension, in two dimensions, at a given instant, or as a function of time. Computers have never discovered, and could not discover, that certain granules evolved and exploded, in a very characteristic manner. Simple cinematographic projection of a sequence reveals this at once, because the central nervous system immediately recognizes two-dimensional objects different from those seen before, and "comprehends" instantly their development in time.*

I now summarize what should be our attitude in the three cases considered:

when an automat can multiply our capacity, our efforts should be applied to the search for the money necessary to replace ourselves as widely as possible;

in cases where the automat must do what man is incapable of doing by himself, we shall doubtless need less money, but effort will be required to understand phenomena and to imagine solutions;

and finally, for heaven's sake, do not let us forget that we are men, that we have brains that offer us marvellous possibilities, and that if, through laziness or blindness, we rely on automats to do everything, then we shall cease to use our brains; we shall cease to be *homo sapiens*; there will be no more men in the full sense; no more men to construct automats; no more automats; nothing.

* Note added after the Colloquium: The *ICSU Bulletin* No. 21, July 1970, publishes the text of the lecture given to ICSU in 1969 by the Soviet mathematician S. L. SOBOLEV, where we encounter (p. 8) the same idea; "The ability to recognise images is a wonderful quality. It is very difficult to impart this quality to a computer".