Max at Seventeen [*]

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I have worked for many years on a computer environment for realizing works of live electronic music, which I named in honor of Max Mathews. Three currently supported computer programs—Max/MSP, Jmax, and Pd—can be considered as extended implementations of a common paradigm I'll refer to here as "Max." The Max paradigm appears to be stable enough now that a printed description of it no longer risks becoming too quickly outdated. We can now usefully assess what Max (the paradigm) does well, what it does less well, and what we can all learn from the experience. The Dartmouth Symposium on the Future of Music Software, organized by Eric Lyon, offers a perfect occasion to start this project. I'll apologize in advance if, for obvious reasons, parts of this article might not seem perfectly objective or impartial. The many others who have worked in or on Max in its various forms and stages should all now get a chance to voice their opinions too.

The Max paradigm can be described as a way of combining pre-designed building blocks into configurations useful for real-time computer music performance. This includes a protocol for scheduling control and audio sample computations, an approach to modularization and component intercommunication, and a graphical representation and editor for patches. These components are realized differently in different implementations; and each implementation also offers a variety of extensions to the common paradigm. On the surface, Max appears to be mostly concerned with presenting a suitable "graphical user interface" for describing real-time MIDI and audio computations. However, the graphical look and editing functions in Max aren't really original at all, and most of what is essentially Max lies beneath the surface.

In my experience at least, computer music software most often arises as a result of interactions between artists and software writers (occasionally embodied in the same person, but not in my own case). This interaction is at best one of mutual enablement and mutual respect. The design of the software cannot help but affect what computer music will sound like, but we software writers must try not to project our own musical ideas through the software. In the best of

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circumstances the artists are around to remind us of their needs, which often turn out quite different from what either of us first imagined. To succeed as computer music software writers, then, we need close exposure to high-caliber artists representing a wide variety of concerns, so that we can identify features that can solve a variety of different problems when in the hands of very different artists.

Many of the underlying ideas behind Max arose in the rich atmosphere of the MIT Experimental Music Studio in the early 1980s (which became part of the MIT Media Lab at its inception). Max took its modern shape during a heated, excited period of interaction and ferment among a small group of researchers and musicians, composers, and performers at IRCAM during the period 1985-1990; writing Max would probably not have been possible in less stimulating and demanding surroundings. In the same way, Pd's development a decade later would not have been possible without the participation of the artists and other researchers of the Global Visual Music Project, of which I was a part. My work on Max and its implementations has been in essence an attempt to capture these encounters in software, and a study of Max will succeed best if it considers the design issues and the artistic issues together.

Background and Influences

The Max paradigm and its first full implementation were mostly developed over the period 1980-1990, drawing on a wide variety of influences. The most important was probably Max Mathews's RTSKED program [Mathews and Pasquale, 1981], some of whose key ideas also appeared in Curtis Abbott's earlier 4CED program [Abbott, 1980]. RTSKED attacked the problem of real-time scheduling of control operations for a polyphonic synthesizer.

While Mathews's earlier GROOVE program [Mathews and Moore, 1970] emphasized the handling of periodically sampled "voltage control" signals, the notion of control in RTSKED was of sporadically occuring events which caused state changes in the synthesizer. For instance, starting a note in RTSKED might involve setting the frequency of an oscillator and triggering an envelope generator. This is similar in style to the "note card" approach of the Music N languages, which have an explicit, instantaneous action time, and are hence better suited to describing a keyboard instrument, for example, than the continuously changing position and downward force of a violin bow.

The main problem addressed in RTSKED was how to replace the note card in the situation of real-time performance where the action time isn't predefined. (Other parameters might not be predefined either, but the chief difficulty seems to be presented by the time parameter). RTSKED modeled the performance as a collection of tasks running in parallel. For example, each task might have responsibility over a specific synthetic voice. The timing of the tasks was controlled by *wait functions* and *triggers*. Only one task ran at a time, but the running task could at any time relinquish control by calling a wait function, specifying a trigger to wait for. Triggers could come from real-time input (the keyboard, for example) or be "fired" by other tasks.

This separation of the real-time contol problem into separate tasks was a key advance, necessary for the computer to act as a musical instrument. Previously, computer music programs (and indeed almost all computer programs in general) enforced a sequence of actions on the user. The separation of the program into parallel tasks permitted the user to control the sequence of execution of the program by selecting which task to trigger next. For example, in a multi-tasking environment we could describe a piano as 91 tasks, one for each key and pedal. The performer—the piano user—chooses in which order to trigger the 91, and how many times they will be triggered. The piano enforces no pre-determined sequence.

This notion of task can be seen clearly in the boxes of the Max paradigm, which "trigger" each other via their connections. The idea predates the invention of MIDI (and Max was never conceived as a MIDI program), but the availability of MIDI I/O for Macintosh computers was convenient for early Max users because MIDI shares the sporadic quality of control events which have their roots much earlier in the "MUSIC N" programs (and even much earlier still, in the well tempered clavier keyboard that MIDI models). The parallelism so visually apparent in a Max patch is intended to allow the user to make computer programs that follow the user's choices, not the program's. This was necessary so that Max patches (the programs) could work as musical instruments.

A second, crucial influence was that of my teacher Barry Vercoe, under whom I studied between 1979 and 1987. Vercoe, himself a student of Mathews, is most widely known as the author of Csound (originally called Music 11), but his less widely acknowledged work on real-time computer music systems—dating back to the mid 1970s with the design of a real-time digital synthesizer, and continuing today—will perhaps someday be acknowledged as his most important contribution to the field.

Most of the advances in Csound over previous MUSIC N languages lay in its highly refined control structure. Although other MUSIC N systems were in some ways much more flexible (Music 10, for instance), their flexibility derived from allowing the user to write code directly in the underlying implementation language—often the machine's assembly language. Csound, on the other hand, presents constructs in its own language for solving musical control problems. Some of these constructs look baroque (`tigoto` for instance) but the central concepts—initialization, reinitialization, and performace—provide a way to specify control structure and sample computation in a tightly integrated way.

This thoughtful approach to control issues also guided Vercoe's development of the Synthetic Performer [Vercoe, 1984, Vercoe and Puckette, 1985], which first ran on a 4X machine at IRCAM. The Synthetic Performer demonstrated real-time *score following*, in which a computer performer automatically synchronized itself with a live player playing a different part. Roger Dannenberg discovered score following independently and showed it the same year [Dannenberg, 1984]. Dannenberg's algorithm performed the analysis portion of the problem more robustly than Vercoe's. But while Dannenberg's design was only concerned with controlling the tempo of a sequencer, Vercoe's system worked at the audio level, obliging him to tackle the problem of managing envelope generators in the face of changing tempi. A representative example of this problem would be to guide a glissando to reach a specific note on a future downbeat, whose time of arrival is constantly being re-estimated in the face of new tempo information.

By the 1986 ICMC in the Hague, researchers in many centers were showing their work on the abstract problem of scheduling real-time computer music performance [Anderson and Kuivila, 1986, Boynton et al., 1986, Favreau et al., 1986, Puckette, 1986]. The systems proposed differed in their use or non-use of context switching and preemption, the design of queues for scheduled future tasks, the implementation platform and language, and many other respects; but many of the threads that fed into the Max design can be seen there.

Another aspect of Max is its Graphical User Intergace ("GUI"). The Max GUI has many antecedents. In 1980 while studying under Barry Vercoe I saw the Oedit system by Richard Steiger and Roger Hale, apparently never described in a published paper, with which one designed Music11 orchestras using a visual "patch language." Many other graphical patch languages—both for music and for other applications—had appeared by 1987 when I started writing the Max "patching" GUI. Although several specific elements might have been novel, at least in the computer music context, the overall idea of a graphical patch language was not.

Development of Max, Jmax, and Pd

The story of how the Max-like languages got to their current state probably isn't well represented by any one person's understanding of it, but the following first-person history should at least shed some light on things. Others may wish to add to or amend this account.

The first instance of what might now be called Max was Music500 which I worked on in Vercoe's laboratory starting around 1982 and one aspect of which was reported in some detail [Puckette, 1984]. There was no graphical front end. The system consisted of a control structure inspired from RTSKED and a synthesis engine distilled from Music 11. The control and synthesis environments were separate. Control was considered as a collection of *processes* which ran in parallel (logically at least) and could be implemented on parallel processors. The "orchestra" (or *synthesis process*) looked like any other control process, and its communication with the other control processes obeyed the same rules as they obeyed among themselves.

The system was intended to run on machines where the number crunching couldn't be realized in a high-level language. The specific hardware envisioned, the Analogic AP500 array processor, had a bit-sliced microcodable number-crunching engine and a "controlling" microprocessor. The orchestra language was written to be interpreted (in vector unit generators) in the number crunching unit, and the control processes were to be multi-tasked in the microprocessor. The idea of using a multi-tasking control structure came directly from RTSKED.

Music500 never got to the point of making sound in real time. By 1984, when I was still reporting on Music500, Barry Vercoe has written the Synthetic Performer at IRCAM, and he invited me to work with him in Paris in summer 1985. In this way I got access to a 4X machine, then the most powerful digital synthesizer/audio processor in the world, just as it was coming on line in its printed-circuit-board version. The 4X, having no jump instruction, couldn't be made to fit into the Music500 orchestra model (and anyway there was an excellent, text-based "patch language" [Favreau et al., 1986]), so I kept only Music500's control structure in programming the 4X, renaming it "Max" to acknowledge the fundamental influence of RTSKED. There was no graphical programming language (the 4X's control computer had no GUI support and besides I was still skeptical of GUI-based software at the time). The "patch" was specified in Max's command line, simply by concatenating the creation arguments of all the objects desired. Since in that version objects could have only one inlet and one outlet apiece, connections could be specified simply by naming each object and listing its destination objects, by name, in its creation arguments.

One of the first uses I put Max to was supporting Vercoe's Synthetic Performer, a version of which we developed together at IRCAM in 1985. The command-line patch consisted essentially of four objects: a pitch tracker; the score follower itself (whose input was pitches and whose output was tempo); a tempo-controllable sequencer, and a controller for a sampling synthesizer running on the 4X (which acted as an output device roughly analogous to Max's `noteout`).

This 4X version of "Max" made its stage debut in April 1987, in Thierry Lancino's *Alone* and Philippe Manoury's *Jupiter*, which were both premiered during IRCAM's tenth anniversary concerts. That early version of Max imposed some almost maddening limitations. There was a complicated and inflexible compilation process to prepare the 4X parameter updates so that Max could use them. Debugging was sometimes very difficult.

After this experience, I tried implementing the Max control paradigm in two separate Lisp environments, before once again rewriting it as a C program on a Macintosh starting in Summer 1987. (The Macintosh in question was brought into IRCAM by David Wessel, without whose efforts I and the rest of IRCAM might have entirely missed out on the personal computer revolution.) The new Macintosh version of Max, which eventually grew into what is now Max/MSP, was first used on stage in a piece by Frédéric Durieux, I think in March 1988. But it was Philippe Manoury's *Pluton*, whose production started in Fall 1987 and which was premiered July 1988, that sparked its development into a usable musical tool. The *Pluton* patch, now existing in various forms, is in essence the first Max patch.

To realize *Pluton* we connected a Macintosh to a 4X with a MIDI cable, using the Macintosh as a "control computer" and keeping all audio computations on the 4X. We thus did not have to confront the problem of specifying the audio signal patch graphically; we still used the 4X patch language, this time together with *ad hoc* C code to convert MIDI messages to 4X parameter changes. So, because of the limitations of the day (you could have a GUI or a programmable DSP engine but not both in the same address space) Max became a "MIDI program." There was nothing fundamental in Max that was derived from MIDI, however; as far as Max was concerned, MIDI was an I/O interface and nothing more.

The next two steps were taken in parallel. First, Max was commercialized through the efforts of David Zicarelli. Zicarelli has persisted in this project for about thirteen years, withstanding the bankrupcies of two companies, and finally starting his own, Cycling74. The world of computer music software has rarely if ever seen a software developer of greater dedication and fortitude than Zicarelli.

At the same time, I joined a team at IRCAM, directed by Eric Lindemann, charged with creating a successor for the 4X. As Manoury pronounced, "the 4X is an old lady now: still beautiful, but too expensive." Lindemann designed an extremely powerful audio signal processor called the IRCAM Signal Processing Workstation or ISPW [Lindemann et al., 1991]. Among its many advances over the 4X, the ISPW offered a jump instruction. I took advantage of this to add to Max a collection of *tilde objects* to do audio signal processing [Puckette, 1991a].

This forced two changes on the IRCAM fork of Max: it was necessary to port the graphics layer to a different window system; and more fundamentally, it became necessary to separate the "real-time" portion of Max from its GUI: the real-time portion ran on the ISPW and the GUI on the host computer, a NeXT cube. Moreover, the real-time component, which I called "Faster Than sound" or FTS [Puckette, 1991b], had to run on multiple processors without the benefit of shared memory.

By 1991 the time appeared ripe to make Max/FTS available on other architectures besides the ISPW. Over the next two years, Joseph Francis and Paul Foley got Max/FTS running under Unix and the X window system. The Max/FTS project has since been extensively reworked and extended at IRCAM by a team led by François Déchelle, who now distribute their version under the name Jmax.

Meanwhile, I had moved to UCSD in 1994, and, seeing several improvements I wished to make in Max, started writing a new program named Pure Data, or Pd [Puckette, 1997]. I made Pd open-source from the beginning (and IRCAM later did the same with Jmax). For Pd I wrote new tilde objects as in Max/FTS, which Zicarelli then used as a point of departure for what he called "MSP," with which Cycling74's Max also became capable of audio signal processing. (By 1996 or so, generic personal computers had finally become powerful enough to make this worthwhile.)

In about 1995 Mark Danks started developing GEM [Danks, 1997], which has matured into a 3D graphical rendering extension to Pd, now maintained by Johannes Zmölnig. Other unrelated extensions to Max/MSP and Pd are available which deal in various ways with video. So the Max programs are now addressing the visual as well as the audio domain.

Today Max, Jmax, and Pd can be seen as three very different implementations of the same fundamental idea, each with its own extensions that aren't available on the others. It would be ill advised to discuss the relative merits of the three implementations here, since the situation is constantly changing. But it's actually possible to port patches back and forth between the three, so that users who stick to the common ground can at least feel that they will have some options if the specific implementation they depend on falls out of repair.

Design issues in Max

By 1993, Max was in wide enough use to attract the bemused attention of computer science researchers; for example [Desain and Honig, 1993]: "For some time we have been surprised at the success of Max and the enthusiasm of its users." The design of Max breaks many of the rules of computer science orthodoxy, sometimes for reasons of practicality and sometimes of style. In the following paragraphs I'll try to give a rationale and critique of the fundamental elements of Max's design. I'll assume that the reader is familiar with the design as described in [Puckette, 1991a].

Max is more oriented toward processes than data. (There is no built-in notion of a musical "score," for example.) If we think of a Max patch as a collection of boxes interconnected by lines, the expressivity of Max comes from its interconnection and intercommunication facilities, whereas the contents of the boxes themselves are usually hidden from the user. Since the only facilities for storing large amounts of data are encapsulated within individual boxes, one can't use Max as such to see or edit collections of data. To address the clear need for data handling facilities, certain types of boxes such as `table` offer their own editors, in their own windows, each in its own way. (Pd offers a new approach to the problem of data representation, but it would be premature to describe it here.)

Since each type of box is free to store data in its own way, there is no uniformity across Max in how data is stored. Certain *ad hoc* mechanisms are also invented on a box-by-box basis for data sharing; the lack of uniformity of approach is a problem, but on the other hand, enforcing a unified approach might have presented even greater problems.

Officially at least, communications between boxes all take place via Max *messages*, which are extremely simple in structure and standardized in content.

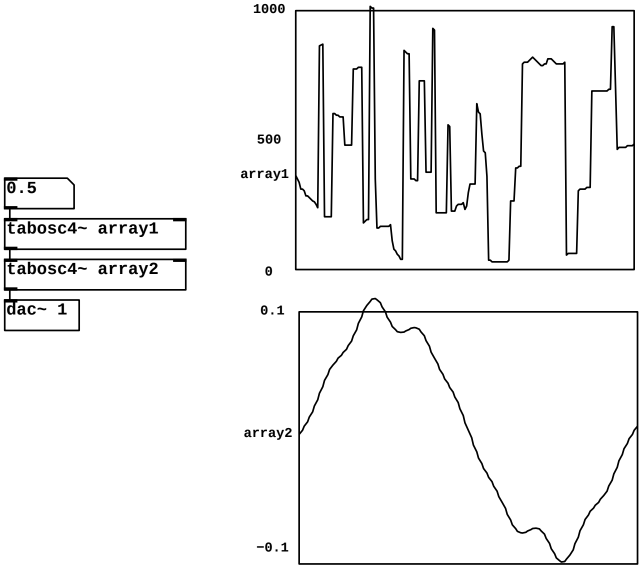
Messages are linear lists of *atoms*, which in turn may be either numbers or strings. (In Max and Jmax the numbers may be of two distinct types; Pd erases this distinction.) Messages are always headed by a symbol, which acts as a Smalltalk-style message selector. (Messages may appear to begin with a number; but for these messages Max always provides an understood selector such as `list`.) There is disagreement among commentators as to whether Max should be considered "object oriented" in light of this message-passing interface, or whether it should be denied the title as lacking many other features common in object-oriented programming languages.

A box's leftmost inlet may take messages with any selector for which the box has a defined behavior. In this way, boxes may have many more behaviors than inlets, and new ones may be added without changing the box incompatibly. Other inlets (besides the leftmost one) only handle one selector each, and should be reasonably few in number; they are best reserved for messages that are frequently needed in a patch (such as the channel number in a MIDI output box). This design represents a compromise intended to increase the ease of interconnection without fundamentally restricting the number of selectors a box may take. Its most important inconveniences are probably the confusion caused by the hidden selectors, and the occasional necessity of prepending the selector `list` or `symbol` to a message.

The extremely simple structure of the messages, as well as the standardization of the use of selectors such as `bang`, are meant to maximize the interconnectability between boxes and to minimize the amount of glue needed. Messages are also easy to type and to read; indeed, the "message box" simply holds a message.

A glaring departure from this principle is in the handling of audio signals. The Max design originally looked at the problem of real-time computer music performance as essentially a control problem, and the facility for patching *audio* signals from one box to another departs radically from the scheme. Max provides a separate data type for audio signals which does not mix smoothly with messages; conversion from audio to messages is problematic and the scheduler treats "control" and "audio" processing separately. I can't offer a better solution than what Max provides. I did once design a message semantic that actually included both modalities in one common generalization, but it appeared to be too general to be useful in practice.

In general, the design of Max emphasizes *text boxes* (objects and messages) in which the user types a message to define the contents of the box. In this respect Max is highly unusual among graphical programming environments. There are at least three rationales for this choice. First, you always will require a text interface of some sort to specify parameters (called *creation arguments* in Max), so to rely entirely on text appears to be the simplest solution possible. Second, once you have more than ten or twenty distinct icons it becomes difficult to remember which icon corresponds to which functionality; text works better mnemonically.



```
0.5
tabosc4~ array1
tabosc4~ array2
dac~ 1
```

Figure 1: A Pd patch with two wavetable oscillators.

Third, the text representation appears to convey more information per square inch of screen than icons can. In most cases, boxes in Max don't rely essentially on dialog windows or other forms of display modalism. Ideally, the text content of a box should determine it entirely—at least at the time of its creation. A central design principle of Max is that, to the extent possible, the patch which appears on the screen should provide a full documentation of what's happening. This is the reason for the avoidance of hidden state (that could be managed via dialog boxes, for example) and for the idea that an object box's entire state (on startup at least) should be seen in the text inside the box.

This is also the reason behind the choice not to make state change in objects persistent. When a previously saved Max patch is repoened, all the values which had been sent to boxes' inlets are forgotten and replaced anew by values supplied by the creation arguments (or failing that, to their default values) because otherwise a patch's behavior could depend critically on the fact that a "+" box, for example, had some specific value left over in its inlet, even after all visible trace of its provenance were gone.

In certain cases (tables, qlists, etc.) it becomes necessary to show more state than the user might wish to see in the context of its use. In these cases Max departs from principle and offers specialized editors, which live in subwindows, to manage the data. This is a compromise, aesthetically unfortunate but necessary because Max's fundamental design doesn't deal with issues of data management.

The Max design strives for simplicity and explicitness throughout. Figure 1 shows an example, in this case implemented in Pd version 0.35: a patch with two oscillators, the upper one controlling the frequency of the lower one. The economy of gesture in this patch is achieved not by designing modules such as `tabosc4~` to be musically intelligent, but rather by making them as transparent as possible—transparency being an opposite of intelligence. The lack of "intelligence" in no way limits the expressivity of the visual language. Instead, expressivity is enhanced by concreteness (the opposite of abstraction), directness, and straightforwardness.

Scheduling

The scheduling algorithm of Max is exceedingly simple, although it took several years to develop. In its final form, it differs from the scheduling algorithm of RTSKED primarily in its approach to data handling. In Max, objects are usually activated by passing messages to them from other objects. The mechanisms for "triggering" an action and for passing data back and forth between objects are unified. (Messages might be empty of data (e.g., *bang*), in which case they may be considered pure triggers.) The unification of data "flow" and triggering was suggested by the piano metaphor, in which the velocity of playing a note is naturally included as part of the fact that the note was played. (This does not make Max a true dataflow language, however; in general, dataflow languages seem not to capture real-time event processing well.)

In addition to the visible patchcords, another source of triggering is the passage of *logical time*. Formally, this appears to the object as just another trigger, although for speed and simplicity it is coded as a plain function callback. Logical time marches forward in a purely deterministic way, irrespective of any real-time delays engendered by CPU load or the operating system. This determinism is crucial for making Max patches debuggable. If something goes wrong, the problem is usually easy to reproduce and track down; and if a patch works in rehearsal it has a good chance of working in performance.

Max follows the piano metaphor also in that objects do not specify what they wait for, but rather objects explicitly choose which other objects to trigger. In other words, the choice is up to the triggering object, not the triggered one (the player, not the piano). Graphically, this is indicated by fan-in at an object's main inlet; the object does not control which line will activate it next. Thus the graphical design and the scheduler match well.

On the other hand, a severe problem comes up for connections that fan out, for which no solution seems wholly adequate. The order in which the fanned-out triggers are fired may affect the aggregate result. Unless the fanned-out messages are given an explicit order of execution, fanout can give rise to indeterminate behavior. One possible solution to this problem, implemented in Cycling74 Max, is to sort the recipients of each single outlet according to their screen position. This has the advantage that one can in principle see how the patch will work directly from its screen appearance, but the disadvantage that merely moving boxes on the screen (to tidy them up for example) can change a patch's behavior. (Furthermore, it's not clear what rule nonlocal connections such as `send/receive` should obey.) Jmax and Pd each behave in other ways which have their own advantages and disadvantages. The best solution is for the user to use `trigger` objects to disambiguate the situation when the order of execution of fanout matters. Perhaps a good way will one day be be found to detect these situations automatically and warn the user of them.

Users of Max are often surprised by the right-to-left order in which multiple outlets of a single box are customarily fired. This is done because a box's "main" inlet (the leftmost one) is used to trigger outputs, and the other inlets are almost always used only to set internal state in the box. For a calculation to work correctly, the leftmost inlet must therefore be triggered *after* all relevant messages have been sent to the other inlets. If one accepts that the first inlet should be the "hot" one, it follows that it should be the last to receive a message, and if a single object is furnishing two or more of the messages, the right-to-left order will be the correct one.

Many thorny scheduling problems arise from the uneasy marriage of audio and control computation in Max. The fact that audio signals are computed in blocks of at least one sample (and usually 64 or more for efficiency's sake) implies that control computations have an inherent grain, in that they can only affect DSP computation on discrete sample block boundaries. This can be a serious problem when building granular synthesis patches, for example, in which control computations might be required to decide the onset time of individual grains.

Another problem is simply that it is inelegant to have audio computation obey different semantics from control computations. Control computations are inherently order-dependent whereas the audio sample clock is predictable so that, for audio computations, dataflow semantics are more appropriate than the message-passing model that Max adopts for control calculations. The two worlds coexist somehow in the same patch, but not without causing confusion and offending computer scientists. In Cycling74 Max and Jmax, audio connections are drawn in a different style from control ones, which at least helps reduce confusion.

Yet another problem is that it is extremely clumsy to perform sample-dependent decision making of the sort that you would use, for example, to trigger a control action at a zero-crossing in an audio signal. When control computations are allowed to interrupt signal computations, the results may be hard to predict or interpret.

All these problems grow in severity when video or computer graphics computations are added. Trying to overcome them might open up fruitful areas of future research. At the moment, however, the Max paradigm seems at least to handle the majority of situations well enough, despite all of its limitations, to be a useful system in practice. To paraphrase Churchill, Max is the worst possible solution, except for all the others that have been tried.

Programming in Max

Musicians have often used Max as a programming environment, at which Max succeeds only very awkwardly. There is no concept of scoping or namespaces in Max; all symbols and their bindings live in one flat space. This decision was made to remove a layer of complexity that didn't seem to be strictly necessary in the context of computer music production, in order to make Max as accessible as possible to people who aren't professional computer programmers.

Further, Max lacks any notion of linear "control flow" such as is fundamental in any real-world programming environment. The whole notion of control flow, with loops, conditionals, and subroutines, is easy to express in text languages, but thus far graphical programming languages haven't found the same fluency or economy of expression as text languages have.

Rather than a programming environment, Max is fundamentally a system for scheduling real-time tasks and managing intercommunication between them. Programming as such is better undertaken within the tasks than by building networks of existing tasks. This can take the form of writing "externs" in C or C++, or of importing entire interpreters (Forth or Scheme, for example). The exact possibilities depend on the implementation.

Musical constructs

The design of Max goes to great lengths to avoid imposing a stylistic bias on the musician's output. To return to the piano analogy, although pianos might impose constraints on the composer or pianist, a wide variety of styles can be expressed through it. To the musician, the piano is a vehicle of empowerment, not constraint. The fact that the output is almost always going to be recognizable as piano music isn't cause for criticism. The computer software analogue is that Max (for example) shouldn't so restrict the musician's doings that the result sounds like "Max," although perhaps we should forgive it for sounding like a computer, as long as sounding like a computer is understood not to imply any stylistic tendency.

To what extent does Max achieve this? It may be too early to know, since Max is still a recent phenomenon when considered in the timescale of musical stylistic development. Still, it is possible to discuss how the Max design aims for stylistic neutrality, and where it might succeed or fail.

On starting Max, the user sees nothing but a blank page—no staves, time or key signatures, not even a notion of "note," and certainly none of instrumental "voice" or "sequence." Even this blank page carries stylistic and cultural freight in at least one interesting respect: the whole idea of incorporating paper in the music-making endeavor was an innovation of Western Art Music, for which many other musics have no use at all. Musical practices which don't rely on paper may in some cases have much less use for computers than have the more

Westernized ones.

Perhaps we will eventually conclude that no matter how hard one tries to make a software program culturally neutral, one will always be able to find ever more glaringly obvious built-in assumptions. But this isn't a reason to stop designing new software; on the contrary, it gives hope that there may be many exciting discoveries still to be made as more and more fundamental assumptions are questioned and somehow peeled away.

Software and technique

On one level, the process of doing computer music is, first, to write software, and then to make music with it. A first measure of the utility of the software is its longevity. However, merely writing software with longevity in mind does not directly serve the music maker. Computer music software can also encode ideas which reach beyond any individual implementation of them. Computer music software's offerings are of two types. They empower the user directly through their presentation as a working environment; but also, they encode advances in computer music practice. The software designer's most direct challenges are to make the software useful to a wide variety of tasks and to make it last as long as possible. But the good, perennial ideas will jump from implementation to implementation anyway.

For example, the wavetable oscillator used in Fig. 1 made its first appearance in Mathews's Music II (two, not eleven) in the late 1950s. Music II was only one in a long sequence of MUSIC N programs, but the idea of wavetable synthesis has had a pervasive influence throughout the computer music discipline.

At its best, software creation is about enabling the user to use the inventions of our day, and not to present him or her with other, alternative inventions that might spring from the mind of the software developer. Invention is an important part of cultural evolution, but we should not confuse invention with software design. Nor should the software designer build his or her private inventions into the software. In situations such as Music II where it was necessary to invent something as part of the software development, the best inventors (such as Mathews) present the invention and its carrier software as two separate, distinct things.

Durability

Two competing desiderata tug at either side of the software developer. On the one hand, we want software to do everything, and our definition of 'everything' grows broader every year. On the other, we require stability, so that we can open last year's e-mail or play a piece of computer music composed six months ago. Every software designer tries to provide the widest possible choice of functionality and simultaneously minimize the risk of falling out of maintenance. The breadth of functionality offered by a new piece of software seems to depend mostly on the ambition of its designer. Its longevity, on the other hand, depends partly on luck, partly on the perseverance of the designer (and his or her employers), and partly on the designer's foresightfulness.

The durability of the musical ideas expressed in a medium such as Max isn't necessarily limited by any specific implementation of Max. The patch of Fig. 1, for example, offers a nearly complete description of its functionality, and any remaining imprecision would be quickly resolved by looking at the document as a text file (this would reveal the exact numeric content of the two tables.) One would not need a running copy of Max or Pd to re-interpret those few lines of text. Ideas expressed in Max can in principle outlast their implementation.

This transmissibility of practice and ideas doesn't depend in any essential way on reuse of code—in contradiction to the preachings of the computer science crowd. Indeed, if object oriented programming in the sense of inheritance structures is essentially about code re-use, there doesn't seem to be an essential reason to be using object oriented coding constructs either. Of course, elegance in code does matter and is a good thing, but it has nothing to do with the creative adaptation of the great underlying ideas which make up the true contribution of computer music to our larger culture. And as to elegance, we can leave it to others to argue the relative merits of different programming techniques and languages.

Musical practice is not hopelessly embedded in music software, any more than the concept of powered flight is embedded in the original Wright brothers' airplane. If we could dig up the original plane it would in no way help us fly any better than we do now. The essential thing is to maintain the practice. The artifact is fun to have around, of course, but only as a museum piece.

External issues

Often, aspects of software which are external to its theoretical design have a strong positive or negative effect on its ultimate usefulness. This may partly depend on the way the software is placed in the social fabric. In this respect the various implementations of Max have occupied a variety of niches. The original program named "Max" was written in a very different world, with much different modalities of software use and dessemination from today's. The existence of three present-day implementations is partly a reflection of the many changes that have taken place over the last seventeen years. One major change is that computer music software has now broken out of the confines of what, in 1985, was a rather insular "computer music commnuity."

Today's low computer prices promise to make possible more subtle encounters than in the past between, for example, Europeans and inhabitants of their former colonies. Instead of heading out into the forest with a computer to record the local artists (as we of Eurocentric cultures have been doing at least since Bartok's time) we can now initiate e-mail conversations. People of almost any community on earth can now record their own music without the help of any modern Bartoks. And people almost anywhere can or soon will be able to get hold of a computer and involve it in their music-making.

This will engender an increasingly audible change in the music of the world. No longer will we hear tapes in which westerners invite non-westerners into the recording studio and later manipulate recordings of them playing their instruments. It's too early to predict what the new music will sound like but it's clear that the door is now open for non-western practices to have a much more profound imprint on electronic music than as mere source materiel. I expect non-western approaches to electronic music to be a source of much energy in the near future.

But we have not as yet caught up with the promises held out by the rapid drop in the price of computer hardware. Yes, you can now buy all the materiels to put your computer together for $400 or so, and with the addition of an amplifier and speakers you're ready to start making computer music. But this assumes you have the necessary knowledge to build a system, locate and install good free software, and then run it. Many commercial interests will work against us, since they would prefer to make the computer cost several thousand dollars and the software several thousand more.

An essential element in the democratisation of computing and of computer music is to nurture local knowledge bases. Certain forward-looking music educators are investing many hours trying to encourage students to build their own computers. I hope someday to see an international culture of home-built computers and homemade computer music software. In the past the well-off West has developed its software, stamped out millions of CDs, and sold them to whomever would buy. In the future, I would like to see the centers of research and learning import software from the rest of the world.

Communities are necessary for knowledge to grow, especially with non-commercial operating systems such as Linux—if you don't have friends also running Linux you're going to have trouble getting it to work for you. But I can imagine a future in which computer music expertise (including how to assemble a machine, install an OS, and run software) is at least within a village or two of most people of the world.

The computer music community is similar to the Linux community in that it can grow among small groups with only occasional need for outside contact beyond what a modem can provide. To empower this it's important that the software not come with its own cultural freight but that it adapt to whatever realities exist where the users live. This is exactly what typifies good software development in general.

This is not what typifies the products of today's software giants. For example, upon starting a commercial spreadsheet program, the user sees something very different from the empty sheet of virtual paper that Max offers. And since the page isn't blank at the outset but is structured, the user will be constrained to move within the ordained structure. The whole business of the software hegemonists is to impose context in the form of proprietary file formats, OS features, and other such constructs. Their concern is *not* letting people do their own thing, and their products will always impede, rather than encourage, progress.

There's no reason people shouldn't sell software (as Joel Chadabe once told me, that is a very effective way of getting it in front of people, even making it available to people who wouldn't be able to get it the way I do which is to search, download and compile it). It's good to be able to have software in a music store, and we're extremely lucky to have a company like Cycling74 so that even if you live in Madagascar you can download a version, run it on your machine, and e-mail someone if at first you can't get MIDI into it. The existence of software companies is an enabling one, as long as they don't engage in predatory practices.

This is complemented by the other kind of enablement which you get with open source software, which is that you can twist it to your own ends to a much greater extent than you can with commercial software—simply because of the absence of the constraints faced by any distributor of commercial software. The marketplace forces commercial software vendors to load their products with features. Each of these features is a potential barrier to portability, to your ability to make it run on you palm pilot or on the microprocessor in your refrigerator or car. More generally, the more bells and whistles a piece of software has, the less easily it can be flexed and put to your own purposes which might not be anything the software designer dreamed of. Even though good software writers can themselves dream of many things, the software user can always think of something else. Although we software designers try above all else to avoid imposing restrictions or obstacles, we never succeed entirely. It might even be that some of the obstacles presented by today's software are so fundamental that we can't even see them.

Computer science or computer music?

Style is important in software: not so much the internal style of programming, but the style with which the software engages the user. We welcome software if its external style pleases us. Well-designed software enhances the workspace in the same way that well-designed furniture does, not only in functionality but also in the stylistic choices that enhance, and don't depress, the quality of our environment.

It is hard to find rational arguments to explain Max's underlying stylistic tendencies toward black and white over color, blank pages over forms, and plasticity over hierarchal structures. Max isn't about computer science but about computer music. Although many computer science results make their way into Max's design, that design doesn't bow to the computer science orthodoxy and its rigid dogma about software design and implementation. Many other software projects in computer music have kept much closer to the computer science line;

however, the most successful ones (Csound, for example) have primarily obeyed stylistic over computer science criteria.

If the success of Csound (and the as yet less proven success of Max) baffle and sometimes annoy the computer science crowd, the failing is a lack of understanding of the importance of style and even aesthetics in software design and implementation. Computer science has never found a metric for determining whether or not a computer program is fun to use.

We speak of "playing" a violin, not "working" it. While music making entails a tremendous amount of work, it has to look like play, even to feel like play, if the musician is ever to survive the ordeals of practice and rehearsal (not to mention the privation of working for little or no pay). If using a computer program feels like working in a bank or a hamburger chain restaurant, musicians won't (and shouldn't be asked to) do it.

The computer should ideally feel in the musician's hands like a musical instrument, needing only to be tuned up and then played. Has Max reached this ideal? Certainly not, and neither has any other piece of computer music software. I hope at least that, in the long term, it will prove to have been a step in a good direction.

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