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Straddling the Intersection

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There is no reason to suppose that a unity of art, science and human values is possible; there is no doubt that it is desirable.

J. Bronowski [2, p.101]

Abstract. Music technology straddles the intersection between art and science and presents those who choose to work within its sphere with many practical challenges as well as creative possibilities. The paper focuses on four main areas: secondary education, higher education, practice and research and finally collaboration. The paper emphasises the importance of collaboration in tackling the challenges of interdisciplinarity and in influencing future technological developments.

In historical terms, music technology is a relatively recent discipline, if indeed it can adequately be described as a discipline at all. It straddles the intersection between art and science, inviting practitioners and academics to balance precariously somewhere between the two. In addition to embracing the musical specialisms such as composition, performance, musicology, music therapy, psychology and education, it also incorporates scientific disciplines such as physics, electrical engineering and mathematics. For people working in any interdisciplinary field there are many practical challenges: adapting approaches to learning and teaching in recognition of diversity within disciplines and an increasingly varied and expanding student recruitment pool; bridging the conflict between specialisation and diversity; initiating and sustaining collaborations and accessing new developments and research despite the absence of shared interdisciplinary terminology and sometimes understanding. For those exploring the intersection of art and technology this situation is further complicated by the rapid pace and expense of technological change. It might seem safer to sit on the sidelines, ignoring technology in the arts, but to do so runs the risk of obsolescence and denies the creative possibilities of technology. ‘One cannot turn one's back on the most significant technological breakthrough in history without risking irrelevance to that history’ [7, p.32].

An examination of western music history demonstrates a precedent for interdisciplinarity and the development and creative application of associated technologies. The advent of the computer, electronic sound generation, recording and processing, was the catalyst which triggered a deeper fusion of music and science, the repercussions of which are clearly felt today in both education and practice. One of the central challenges within the field of education is finding ways to exploit the benefits and creative potential of technology, without losing or compromising traditional musical disciplines and skills.

Secondary Education

For some years, school education in the UK and elsewhere has been subject to a barrage of government directives and achievement targets and has consequently been in a constant state of flux. Changes to curriculum, assessment methods and funding strategies have all had a significant impact on arts education in schools. The government actively encourages the use of computers in teaching, recognising the necessity of computer literacy within the employment market and also the potential of computers to enhance the learning experience. Many local education authorities have found it difficult to provide such equipment without economising in other areas of educational provision. Some schools have been unable to sustain the expense of providing instrumental music lessons for their pupils, and so fewer school children have the opportunity to learn a musical instrument or to play in ensembles. The process of learning a musical instrument is educationally rich and enjoyable; pupils develop academic and practical skills, many of which are transferable to non-musical disciplines.

The personal computer and the electronic keyboard have become the focus of many music classes today, but does the educational value of the computer compensate for the decline in instrumental music making and other musical skills? In the hands of a good music teacher, the value of the computer as an educational tool is undeniable. Pupils can experiment with sound recording, processing and sequencing; they can hear their first compositions realised on MIDI instruments through music notation programmes such as Sibelius and Finale; and they can access educational CD-ROMs and the Internet, providing a wider platform for learning and research. Conversely, many music teachers are unfamiliar with music technology, having completed their musical and teacher training before the technology revolution. In such cases, the investment schools make in music technology is wasted because teachers often fail to realise its full potential. School pupils lose out on two counts: they are denied the benefits of instrumental music making and fail to reap the rewards of computer assisted learning. Unless teachers are provided with the time and support they need to update their skills, music education in schools will continue to suffer. William Hussey sums up the situation well in his review 'Technology and Teaching Music:' 'The infinite potential of computers and their role in the 21st century can be both exciting and daunting, particularly for those who are just barely keeping up with the advancements of today' [10, p.92]. Even when computers are utilised to best advantage, computer technology cannot replace the educational and personal benefits of learning to play a musical instrument.

Another concern in school education is the promotion of technology as a vehicle for learning at the expense of other approaches. Some music software programmes allow pupils to create music without understanding the musical processes involved, providing sound samples, drum loops and so on which can be sequenced together by ear. Whilst such forms of experimentation present opportunities for learning and awakening musical interest, without additional instruction and awareness of musical context, pupils will not realise their full potential or be aware of the scope of musical possibilities.

Such trends are compounded by the fact that many school pupils today are very interested in popular culture music and as a result are eager to emulate this musical genre. Popular music relies heavily on music technology, and so the computer tends to be the preferred vehicle for learning. Whilst an interest in popular music is a valuable starting point for musical education, it should not be seen as an end in itself at such an early stage in learning development. Pupils need to be made aware of many genres of music. Whilst the computer can assist in fostering such awareness, it should not be presented as a substitute for acquiring core musical skills.

It is not surprising, in light of such trends, that there are some music educators who feel that the misapplication of technology has lowered artistic standards. Peter Fletcher's statement that, 'The new cultural invader is technology which . . . is not only endorsing an inartistic approach to art, but is upsetting artistic forms and balances on a global scale,' might appear to be the unreasoned view of a Luddite, but there is some truth behind it [6, p.46]. Fletcher wrote this in 1987, when few schools had access to computer technology. He would have witnessed the increasing promotion of technology within the arts, and it is clear that he feared for the future of school education and 'artistry' in general.

Higher Education

Music technology courses attract students from a broader range of backgrounds than traditional disciplines. Catering for the disparate needs of music technology students is something of a juggling act. Some students who have received formal musical training may be interested in technology but have little experience of it and may be regarded as somewhat 'technophobic.' Rather like vertigo sufferers daring to bungee jump, they launch themselves into the unknown in an attempt to conquer their fear. By contrast, at the other end of the recruitment spectrum, a significant percentage of students are interested in the science behind music technology, harbouring ambitions to design the audio software and hardware of the future. They enrol on music technology courses to gain further knowledge of computer programming and electronic engineering, focusing on the creative applications of audio technology.

Lying somewhere between these two caricatured extremes are a significant number of students, of varying academic ability, who, though very familiar with the practical uses of technology, lack musical training or any understanding of the science of technology. Many are purely interested in producing, performing and composing popular culture music. A good proportion of these students demonstrate a preference for vocational and practical training and show disinterest in academic music and contextual studies, which can create difficulties for educators attempting to plug students' knowledge gaps. Unless educators can engage with all these students respectively, encouraging them to step beyond their 'comfort zones' to explore music in all its forms, students will never acquire a broad skill base. Inevitably there are graduates entering the music business who lack the versatility of skills which would enable them to adapt to varied musical contexts and careers. Whilst technology offers a diverse range of students access to music, it can result in a very 'lopsided' educational approach in which important musical disciplines are forsaken.

One common denominator unifies all students studying music technology today: an unshakeable belief that the future is paved with computer technology. Like seasoned time travellers embarking on an expedition into the future, they realise that survival depends upon preparation and training. The allure of music technology today for them is undeniable, and as a result, music educators are presented with a unique opportunity to explore music with a new audience who would never have entered formal musical education. In this context, technology can be seen as a great enabler with enormous educational and creative potential for people of all abilities, or as one educator put it, ‘the extensive array of new technologies provides both students and educators with new powers and incentives for showing the world what is on their minds’ [16, p.42].

One way to ensure that music technology courses meet the diverse needs of students and support the development of musicianship is to re-examine their structure. Many degrees today are structured around a modular framework in which students must pass enough modules to earn the required number of credits. Music technology degrees differ dramatically in terms of course content: BSc programmes focus on science-based modules, whereas BA and BMus programmes tend to offer a larger proportion of music-based modules. Students generally have to complete designated ‘core’ or compulsory modules and then select from a range of optional choices. Within such a framework, a set of core foundation modules at level one can be designed specifically to meet shortfalls in student knowledge. During induction week, students can be streamed into the appropriate foundation modules according to their levels of musical and technical knowledge and experience. Such modules become progressively more advanced until skills shortfalls are less pronounced.

Concert series or extensive designated listening, presenting a wide range of musical genres and styles, should be incorporated within core modules. Whilst this is common practise on most music courses, many music technology courses leave this responsibility almost entirely to the students themselves or choose to focus exclusively on music composed within the last century and fail to monitor or develop related skills such as aural perception and analysis.

Modules exploring a particular genre of music should be made as inclusive as possible, demonstrating parallels with other musical styles. This allows students to explore new avenues of creativity in their own work, expands their skill base, guards against a tunnel-visioned perception of music and deconstructs a compartmentalised approach within the degree structure itself. For example, a study of drum tracks and programming could be used as a springboard to explore rhythm in general; an introduction to polyrhythm (the superposition of different metres or rhythms) could become a vehicle for exploring modern jazz, medieval polyphony, world music (e.g., Ghanian drumming) and the works of composers such as Stravinsky, Hindemith and Bartok.

Student collaborations should be encouraged throughout music technology degree programmes. Despite the interdisciplinary nature of music technology, it can become a very isolating field; many long hours are spent alone in soundproofed studios or in front of computer workstations and related hardware. Collaborative projects can combat this tendency and respond to the diversity of the student body and the subject area itself. Well-designed projects based on real-life case studies or commissions allow students to work to a given brief and completion deadline and provide insight into the realities of working commercially. For example, an audio-visual module may include a commercial group project in which individual students or groups each take responsibility for a different facet of the project, such as graphics production and processing, soundtrack composition, sound recording, design and sound effects, postproduction and quality control. On completion, projects can be presented and subjected to peer and staff review, providing feedback for future work.

Unfortunately, electroacoustic and acoustic composition are sometimes presented as opposing forces. Recent interest in real-time human-computer interaction is going some way towards dispelling this perception, but it is important that music technology courses do not allow one to dominate the other at undergraduate level. Whilst specialisation is natural, it should not be encouraged too soon, before students have explored the diversity within their subject area.

In addition to providing new ways of manipulating and organising sound, computer technology can also be used to develop and explore more traditional techniques. For example, arranging and orchestrating for acoustic instruments can be much easier with computer technology than without it. Programming and sequencing MIDI instruments is not dissimilar to writing for acoustic instruments. Students can be encouraged to familiarise themselves with the timbres, techniques and ranges of the instruments the MIDI sounds substitute, considering which combinations of instruments work well together as well as their spatial positioning and dynamic level within the mix. They can also be encouraged to find ways of enhancing the quality of MIDI sounds through additional signal processing. Such an approach prepares students for working with acoustic instruments whilst improving the quality of their MIDI work.

There is tremendous scope for the development of new educational software which could assist educators in meeting deficiencies in musical knowledge. Computer technology could be exploited far more to facilitate the acquisition of key skills. The computer program MacGamut by Ann Blombach is designed to develop aural skills and demonstrates the educational potential of computer technology in supporting the traditional as well as the new [10, p.93]. History, analysis, harmony, counterpoint, orchestration and composition can all be supported through well-designed educational software. When such tools are packaged in the right way, with interesting graphic user interfaces, intuitive controls, approachable and progressive content with effective online support and feedback facilities, students are more likely to explore key skills independently, and staff have a new teaching resource at their disposal.

Increasingly, music technology lecturers are developing online help utilities to support students who lack basic music skills. These range from simple help facilities offering additional information through to complete online courses [10, p.93]. In addition to tackling deficiencies in musical knowledge, online instruction can be very beneficial for mature students and students with disabilities or illnesses. Internet technology is also useful in lectures, seminars and workshops. Replacing static PowerPoint slides with non-linear, expandable HTML pages allows for greater adaptability, as certain links only need to be activated if there is a particular shortfall in student knowledge or understanding. Pages may also be designed to test and review levels of student understanding or skill; questions or exercises may be linked to step-by-step answers, practical realisations, technical guidance and so on. The benefits of this approach are considerable when attempting to meet the demands of subject and student diversity. The technique works just as well offline as online and is ideally suited to the presentation of audio-visual and technical material. The only real drawback is the amount of preparation time involved, but once a few simple web pages have been constructed they can be developed gradually and updated over time.

Educators should harness the educational potential of technology to facilitate learning rather than presenting it as a substitute for learning. Much can be learned from the study of educational practice in other disciplines and from conferences, forums, journals and other publications which address generic issues regarding interdisciplinarity and technology. The challenges of music technology education are very real, but then so are the rewards, and in the current climate of discussion and exploration, the future seems increasingly bright.

Researchers and Practitioners

Just as educational institutions juggle the demands of music technology as both a musical and technical discipline, so researchers and practitioners face many of the same problems. For many working 'on the cutting edge' of music technology today, the line between art and science, if one exists, has become almost indistinguishable. There are very few people who are equally at home in both worlds, and yet as a discipline, music technology seems increasingly to demand equal facility. It is this duality that represents one of the central challenges for people working in the field. Choosing where to specialise can be rather like investing in the futures market; fashions for particular types of software, hardware or programming languages fluctuate with alarming frequency. Despite the additional creative scope these changes may introduce, each change represents a significant learning curve, and consequently research can be slow and frustrating.

Leading music technology and audio engineering journals contain articles written by researchers from a range of scientific disciplines such as engineering, physics and mathematics. The findings of many of these articles would be of great interest and potential usefulness to musicians, but they are couched in such a way that many musicians are unable to understand the content. Lists of mathematical formulae, data, circuit diagrams and source code may clarify content for scientists but will almost certainly mystify and confuse most musicians who lack scientific training. Equally, articles written by musicians that include musical terminology and notation and assume a background knowledge of music or analysis techniques could be confusing for the scientist.

In a recent science-based article, describing an interactive, movement triggered composition system, the authors write that, 'newfound freedom is often paradoxically accompanied by stifling restrictions. Researchers, musicians, composers, choreographers, and dancers are just beginning to grasp the possibilities these new technologies offer' [3, p.26]. The primary restriction is not an unwillingness to grasp the potential of new technologies, but rather an inability to grasp new developments in the absence of a shared language and understanding. The authors go on to acknowledge that 'there remains a distinct need for a simpler, easier to understand . . . mechanism that mediates between sound and motion' [3, p.26]. This statement is followed by four 'clarifying' pages of equations based on the Frenet-Serrett theorem, followed by sample Escamol source code and various control flow diagrams showing the architecture of the system. Ironically, the paper represents one of the more approachable presentations of recent technology research. Obviously it is important that academic standards are not compromised and that researchers from any background have the opportunity to present their findings in detail, but interdisciplinary researchers and practitioners risk excluding and alienating the very people their research should be targeting, namely those who could realise the creative potential of their findings.

Practitioners must also grapple with the inherent duality of music technology. Advanced audio software and hardware for synthesis and digital signal processing can only achieve controlled and worthwhile results if the user understands the theories behind the processes. Some of the most powerful audio software requires the user to learn complex computer programming languages, which allow them to design synthesis and signal processing instruments from scratch. Designing instruments in this way demands an understanding of the scientific theories behind audio processing and synthesis. Those who wish to realise their instruments in real-time, for example in a live performance, must first be able to write efficient code which will run without a perceptible delay during the performance, a skill which requires time and aptitude to master.

More user-friendly hardware and software offers presets which allow people to experiment with a selection of processes, but in order to achieve more unusual results, customisation inevitably becomes necessary, and customisation requires understanding. There are some musicians who cannot realise their creative goals using existing software or hardware. They seek to develop new technologies for very specific applications but lack the necessary engineering knowledge to realise their ideas. Equally, audio engineers may wish to test and apply their ideas in musically creative contexts but lack the skills to do so. It may also be the case that engineers working in areas such as speech recognition or artificial intelligence may not have considered applying their work in musical contexts.

Gardner's comment that 'the greatest enemy of understanding is coverage' is central to people working in any interdisciplinary field [4, p.44]; there can be so much ground to cover that depth of understanding becomes compromised. There are many areas of specialisation within one discipline alone. Combine two or more disciplines to form a hybrid such as music technology and the conflict between specialisation and diversity soon rises to the surface. People who venture across this turbulent intersection of art and science often have to travel so far that some lose sight of those they left behind and lose the ability to communicate with them in terms they would understand. 'Jack of all trades and master of none' is one description most people would wish to avoid and yet a choice for wider understanding and diversity over specialisation could well produce this very result.

The Need for Collaboration

Music technology has embraced both art and science in what appears to be an arranged marriage; both parties have agreed to the union but know little about one another, coexisting awkwardly under the same roof, bumping into each other more often than they would like but ultimately hopeful of a happy and long-term future together. The only way such a future can be achieved is through understanding and dialogue. Collaboration is the primary vehicle for dialogue of this kind; it allows for specialisation and also improves wider understanding. Ideas and expertise are shared in the pursuit of common goals. Artists and scientists may explore projects together which could not have been realised or even envisaged in isolation.

Edgard Varese saw the need for composers and electricians to collaborate in pursuit of new instruments which would enrich 'our musical alphabet' [15, p.6]. In an interview for the *Christian Science Monitor* (1922) he stated that, 'the composer and electrician will have to labor together . . . ' in order to realise new means of expression [15, p.6]. The composer Joseph Schillinger also saw the potential for wielding science in the pursuit of musical goals. In an article aptly entitled 'Electricity, a Musical Liberator' dating from 1931 he writes:

The growth of musical art in any age is determined by the technological progress which parallels it. Neither the composer nor the performer can transcend the limits of the instruments of his time. On the other hand technical developments stimulate the creation of certain forms of composition and performance [15, p.7].

Schillinger raises two key issues in his consideration of music and technology: limitation and liberation. Whilst it is true that musicians are confined by the technical limitations of their time and are therefore dependent upon the scientific community to expand the scope of technology, it is also true that technology liberates musicians in the discovery of new approaches to composition and performance. Just as technology has evolved, so have the challenges associated with it. Had Schillinger lived to witness the technologies of today he might have written his article very differently; he might still have written about the paradox of limitation versus liberation, but the source of limitation might have had less to do with technological advancement than with a greater need for understanding and collaboration.

Engineers as well as musicians have recognised the growing need for collaborative links between the arts and sciences. The engineer Billy Kluver, who became the catalyst for the art and technology movement that was launched in 1960 at the Museum of Modern Art in New York, wrote that, 'the use of the engineer by the artist is not only unavoidable but necessary' [12, p.35]. He uses the term 'interface' to describe the working association between artists and engineers,

The new interface I will define is one in which the artist makes use of the inventiveness and skills of the engineer to achieve his purpose. The artist could not complete his intentions without the help of the engineer. The artist incorporates the work of the engineer in the painting or the sculpture or the performance [12, p.33].

The 'interface' Kluver proposes recognises technology as an integral part of the finished artistic creation. In a society of which technology is so much a part, Kluver sees the extension of technology from life into artistic expression as necessary for technology as well as art. 'First the artists have to create with technology because technology is becoming inseparable from our lives . . . second, the artists should use technology because technology needs artists' [12, p.38].

Kluver's belief that technology and art are mutually dependent might seem surprising in today's society. From our earliest years, learning is presented to us in clearly demarcated subject packages, prioritised according to perceived importance. Mutual dependence will not be the natural outcrop of a generation raised in an educational culture founded on partition (the partition of one discipline from another or even modular partitions within a discipline). Kluver recognises that shared projects combining engineering and art have the potential to change the way we think about technology and its role in our future lives: ‘the use of the engineer by the artist will stimulate new ways of looking at technology and dealing with life in the future’ [12, p.38]. Kluver clearly sees the ‘interface’ between art and technology as vital to future developments.

In describing his contemporaries, Kluver paints a picture of an artistic community passively viewing a technology show, occasionally grasping at interesting developments but without really engaging with these developments. They are recipients of technology rather than shapers of it: ‘art remains a passive viewer of technology. Art has only been interested in the fallout, so to speak, of science and technology’ [12, p.35]. We have now entered a new century, and yet Kluver's statements still seem relevant today. Artists, though interested in technology and eager to explore its creative applications, could be involved far more in the development of future technologies. Unless artists and engineers can come to see their mutual need of one another in the pursuit of shared creative and technical goals, real progress will be limited.

Nowhere is the need for collaboration more evident than in the development and creative exploitation of interactive technologies. The human obsession with interactive technology can be seen in many works of science fiction which portray a future in which the division between human and machine becomes blurred. The machine ceases to be regarded as something ‘other,’ outside of ourselves, becoming an integrated component of daily life in all its facets. Such fictional visions of the future, fuelled by our fears as well as our aspirations, have some basis in the recognition of the fact that effective human-computer interaction is a driving force in the development of new technologies. As interactive technology gains an increasing hold on our society and way of life, it becomes more essential that the artistic and scientific communities meet together to discuss future developments in technology and how they will affect all our lives.

Whatever the future holds, past history and recent developments tell us that technology will increasingly be used as a vehicle for human and artistic expression. In order for such forms of expression to be accessible by and representative of society as a whole, interdisciplinary collaboration and education become vital.

Collaborative and Interdisciplinary Models

If the solution seems so obvious, why then do there appear to be so few opportunities for cross-disciplinary collaboration or so little readiness to engage in them? There may be a number of reasons: the fear of losing ownership of one's ideas; pressures of time; involvement in solo research projects; a lack of contacts or sufficient reputation to secure collaborative partnerships and funding; geographical isolation; lack of support, expertise and interdisciplinary links at institutional level; or, finally, the misguided perception that interdisciplinary collaborative work is less rigorous and academically demanding than specialised independent projects. The potential for collaborative projects between science and music to break new ground, particularly in areas such as artificial intelligence, is enormous. What better test of computer intelligence could there be than a computer that can perform as part of an improvisatory ensemble, listening to other performers and responding spontaneously to them, with the ability to learn from each performance experience?

Whilst an increasing number of institutions, such as MIT, have recognised the potential of collaborative projects and have been progressive in the formation of formal links between different disciplines, others have not. Without such links, large-scale collaborations become very difficult to support and the responsibility for initiating projects falls to the individual. Finding research partners or practitioners with the necessary skills and expertise can seem an impossible task. One does not find adverts for ‘music researcher, likes DSP and synthesis, would like to meet similar, must be good with computers, possibly for long term relationship’ in the classifieds very often! Whilst there is no easy solution to these difficulties, many individuals and organisations are successfully grappling with the challenges of collaborative and interdisciplinary projects; an examination of their work can be useful in establishing possible solutions and examples of best practice.

One of the most interesting and prolific musical collaborators was David Tudor. He began his career as an avant-garde pianist but then turned his attention to composing live electronic music, associating closely with the composer John Cage and Merce Cunningham's Dance Company. He was fascinated by analogue rather than digital technology and used electronics creatively as musical instruments:

The defining characteristic of Tudor's music is that the source of the sounds is the behavior of the electronic circuits themselves: oscillations, amplifications, modulations, frequency filtering, attenuation, switching. By interconnecting discrete units that perform these various functions, Tudor builds up his musical instrument. [13, p.1]

Over the course of his career he collaborated with many artists, scientists and engineers. His technical expertise assisted him in collaborations with engineers from different fields, including Bell Laboratories and later, during the 1990s, the Intel Corporation, a collaboration which resulted in the Neural Network Synthesiser [9, p.1]. He was also keen to collaborate in the creation of works with visual elements such as television and film, dance, theatre, lasers and lighting systems.

Tudor's final and arguably most significant collaborative work was ‘Toneburst: Maps and Fragments.’ The artist Sophia Ogielska produced the images using a software program developed by Andy Ogielski. The program was expanded several times to meet the creative and technical requirements of ‘Toneburst.’ Despite the collaborative nature of the project, Tudor regarded it as uniquely personal, describing ‘Toneburst’ as a direct translation of his mind into music [1, p.3].

Tudor had the technical expertise to produce interdisciplinary works in isolation, and yet he chose to collaborate in order to widen the bounds of exploration and creativity. His willingness to experiment and his eagerness to associate and work with other artists and scientists ensured a growing network of collaborative and influential projects throughout his career.

Digital technology has inspired a number of significant collaborations exploring audio-visual interaction. Jack Ox, a New York-based artist, collaborated closely with David Britton in realising her 21st Century Virtual Reality Color Organ. Britton handled ‘the graphics programming and the meta-architecture of the programming structure,’ while Ox was responsible for the ‘concept, visual images, musical analysis, visualization systems and texture maps’ [17, p.2]. Robert Putnam of the Scientific Computing and Visualisation Group at Boston University worked on the ‘interactive, kinetic sound placement and 3D localization’ [17, p.5]. The collaboration received considerable support from other bodies such as ASCI (Art and Science Collaborations, Inc.), Ars Electronica and others. Technology-based collaborations of this sort are dependent upon finding sufficient funds and technical expertise. Thus whilst Jack Ox's work demonstrates what may be achieved in an equal partnership between art and technology, it also illustrates the necessity of securing backing from external bodies, some of whom specialise in supporting collaborative projects and have a wealth of experience and advice on offer.

Lemma II is representative of a growing body of performance works exploring real-time human-computer interaction. The work is the result of a collaboration between Vibeke Sorensen (visual artist), Rand Steiger (composer), Miller Puckette and Mark Danks (researchers) and a group of seven performers. Software is used to analyse audio input in real-time, transforming it into control data which is used to manipulate graphic images in 3D. At its 1999 performance at the Miller Theatre in New York, performers were located at opposite ends of the continent linked via an ISDN connection between the Intel Corporation in Oregon and the Miller Theatre [8, pp.85-6]. Whilst the logistics of such a performance may be difficult to organise, it does suggest new possibilities for collaborative projects in which collaborators or performers are isolated by location. As Internet and communications technologies improve, long-distance collaborations involving performance and interactive elements could offer new avenues for research and performance on an international scale.

EyesWeb is an example of a collaborative science-based software project designed with artistic applications in mind. Seven researchers collaborated in the development of the system, also drawing extensively on existing research. It is ‘a modular system for the real-time analysis of body movement and gesture.’ The resulting information is used to ‘control and generate sound, music and visual media, and to control actuators (e.g., robots)’ [5, p.57]. The project explores expressive gesture and visual languages and is designed to suit applications such as dance, theatre and art installations. Interactive real-time projects of this kind demonstrate the need for collaboration in order to pool sufficient resources of expertise and specialism in development and testing. EyesWeb is typical of collaborations initiated by ongoing research projects in and between different universities; students and staff share research in the pursuit of common goals, standing on the research of those preceding them. For young researchers, this represents a supportive environment for collaboration and can provide valuable experience for future projects.

Universities and other institutions of higher education play a vital role in initiating and nurturing collaborative research and practice. Many host interdisciplinary conferences which present researchers with valuable opportunities to share knowledge and make contact with like-minded individuals. Online discussions often continue beyond the events themselves, supporting ongoing research and collaboration. Some universities have forged interdepartmental links among staff from different disciplines teaching within the same degree programmes and collaborating on shared research projects. MIT's Media Lab represents one such enterprise, but there are other less well-known institutions creating nurturing environments for cross-disciplinary collaboration, such as the Ammerman Center for Arts and Technology at Connecticut College. The centre draws its principal researchers from the disciplines of art, music and computer science, but further researchers are drawn from other subject areas such as zoology, chemistry, physics, mathematics, dance, theatre and languages. The educational programme is taught collaboratively and is designed to encourage collaboration amongst the students. The centre also places great importance on outreach to the wider community. Students engage in a broad range of projects, developing a wide skill base whilst enhancing their employment prospects [11, p.104].

Beyond the university system there are a number of interdisciplinary collaborative research centres and interest groups such as: Composers Inside Electronics; Centro Ricerche Musicali (CRM) in Rome; Institut de Recherche et Coordination Acoustique/Musique (Ircam) in Paris; and others. They work to develop new technology and to support musicians in the creation of new music. Other organisations support musicians working with technology in education such as the Association for Technology in Music Instruction (ATMI). More eclectic collaborative groups such as Uavisiliu, an experimental multimedia group, aim to combine a wide range of elements within their performances, including dance, poetry, music and the visual arts.

Commercial organisations also present useful interdisciplinary models, illustrating the effectiveness of digital technology in the arts. Why Not Associates is a multidisciplinary design studio based in London. They encourage an experimental attitude in their work, believing that potential clients are receptive to adventurous design [18, pp.52-5]. Second Story is an organisation that has won many competitions for its interactive web experiences and other media [18, pp.158-61]. The Apollo Program, founded by Elliot Peter Earls, is an experimental media studio, type foundry and design studio which explores creativity through the application of digital technology [18, pp.164-7]. Michael J. Schumacher and Ursula Scherrer's Studio Five Beekman and its successor Diapason were set up in New York to present computerised sound installations. Diapason continues to show a diverse range of exhibits and does much to encourage composers and multimedia artists. Evolution, a strand of the Leeds International Film Festival, 'aims to explore and contextualise contemporary digital and time-based arts practice' [14]. It presents films, discussions, installations and other events over a number of days, bringing together leading practitioners and showing works both old and new.

There are a number of individuals who thrive at the intersection of art and technology and yet choose to work alone. Many of these have a scientific background, but there are some from the arts. Jakob Brandt-Pedersen is an artist who is interested in exploring audio-visual correlation. Rather than designing new software to achieve his creative goals, he uses MAX, an interactive object-oriented MIDI programming environment [18, pp.136-9]. The work of Adriano Abbado is particularly intriguing; he is an artist and musician who focuses on the interaction of aural and visual objects [18, pp.152-7]. His MIT thesis contains examples of ethereal, computer-generated visual manifestations of sound. The artist Lee Roskin works on 'musical light shows' incorporating video footage, audio equipment, computers and other devices. Roskin acts as the interface between the music, the visuals and the computer [18, pp.162-3].

Whilst it is relatively easy to find examples of individual scientists developing new technologies for arts-based applications, examples of artists and musicians engaged in similar independent work are much less common. As educational establishments recognise the need to equip students with a balanced and broad repertoire of skills in the arts and sciences, those who find collaboration difficult, for whatever reason, will increasingly be able to explore some interdisciplinary projects independently.

Clearly there are many examples of successful and fruitful collaborations, but for those people struggling to get collaborations 'off the ground,' far more could be done. The initiatives already in place are very effective, but more are needed, particularly at regional and national levels. There could be collaborative databases, on- or offline, listing individual or group research interests and indicating those people seeking collaborative partners. Databases of this sort could be organised regionally as well as nationally. Regional centres or 'think tanks' could be set up specifically to encourage interdisciplinary projects and collaboration. They could play a commercial, educational and outreach role. Initiatives of this kind, provided at local level, would answer some of the challenges for those people 'straddling the intersection,' potentially paving the way for an exciting and interactive future for humanity and its machines, a future in which, 'rather than positing the machine as an inhuman "other," . . . we can coerce the machine into being an extension of the compositional and performing self' [7, p.33].

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[1]
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