COMPUTER CHOREOGRAPHY FOR ELECTRICALLY FIRED SHOWS

Will Harvey, Ph.D.
Finale Fireworks
165 Hawthorne Ave
Palo Alto, California 94301 USA
will@finalefireworks.com

ABSTRACT

For more than a decade, computer based visual simulation of fireworks displays has enabled choreographers to create pyromusicals that would be impossible without seeing what the display looks like while designing and laying out the show. The results are seen all around the world in computer fired shows at major celebrations and fireworks exhibitions. In reality, though, computer fired shows represent only a tiny fraction of the fireworks shows every year. The vast majority of shows occur on major holidays, making it economically impractical for display companies to carry enough computer firing systems and trained operators to put on that many computer fired shows simultaneously. Consequently, there are many people in America and other countries who have never even seen a pyromusical or the type of choreography that computer simulation makes possible.

Is computer choreography therefore inherently limited to the big budget displays? If you associate computer choreography with computer firing, the answer appears to be yes, but what if you break that association? Let us rethink how computer choreography might apply to the tens of thousands of non-computer fired displays every year. Beginning with the assumption that the majority of a display company's shows are hand fired or electrically fired, we will illustrate how innovations in choreography software can improve the safety, quality, and profit of these non-computer fired displays.
INTRODUCTION

This paper challenges the assumption that computer choreography and visual simulation apply only to big budget, computer fired shows. The vast majority of shows are not computer fired, so if process and tool improvements are to be found, these non-computer fired shows represent a large opportunity.

We will focus our attention on electrically fired shows, leaving aside the hand fired shows on one side and the pyromusicals on the other. We will refer to electrically fired shows with and without musical accompaniment interchangeably, as the arguments apply to both. When we speak of choreography, we will mean the type of choreography that is physically possible to shoot electrically, which represents a middle ground between no choreography whatsoever and the complicated firing patterns that are possible only with computer firing. This middle ground potentially represents a large economic opportunity for the industry.

Choreographing electrically fired shows is not itself a new idea. People do it all the time. However, in this paper we explore a more expansive role that computer choreography systems can play, extending from site layout tools to sales tools and inventory management systems. We illustrate how innovations in choreography software across a spectrum of areas provide immediate benefits in the safety and quality of displays, as well as economic benefits from better sales tools. Finally, we discuss how operators can play a larger role in choreographing shows, and the economic advantages and other benefits that can arise from this model.

The paper follows these lines in three main sections. The first section covers safety benefits from recent software innovations. The second section illustrates the quality of show benefits that can be expected from choreographing electrically fired shows. The third section covers the economic benefits.

SAFETY

While the nature of fireworks is inherently unpredictable, most fireworks accidents are said to be preventable with better preparation. Choreographing a show on computer has the salutary side effect that information about the show such as the location of the launch positions, calibers of shells, and angles of mortars can be used for purposes other than the choreography. Notably, this information enables a variety of computer tools that can dramatically improve the preparation of inexperienced crew volunteers, facilitate communication with the fire marshal or authority having jurisdiction (AHJ), hone the judgment of the operator, and remind the operator of considerations that arise from the layout and the physical properties of the shoot site.

Preparing Crew Volunteers in Advance
Most operators are familiar with the task of educating and preparing inexperienced crew members for setting up a show. It is not uncommon for completely new crew members to show up at the shoot site without any idea of what their task entails, sometimes without even the basic understanding of what a shell, rack, or mortar is.

![Figure 1: Plan view of a launch position and detail view of a pod, as seen in Finale Fireworks.](image)

Once a show is choreographed on computer, the number of shells at each launch position is known, in addition to the wiring connections, and mortar angles. It is a short step for the computer to give the choreographer a one-click "add racks for shells" option to lay out the required racks visually on a plan view of each launch position, using racks of default configurations according to the equipment inventory of the display company. At that point, all the information is available for the computer to create 3D diagrams of each launch position with detail views of each group of racks, or pod.

The above examples illustrate a launch position (LP) overview diagram on the left, showing two pods labeled #1 and #2. On the right is a detail view of pod #2, showing the four racks, their angles, and their wiring requirements.

A complete visual report with a diagram of the shoot site, detail views of each launch position, and then further detail views of each pod can then be generated as a PDF document and sent via email to all crew members before the day of the shoot. The operator can plan out the responsibilities of each crew member and tell even the completely inexperienced crew members something of the form, "Here is an overview of the shoot site you will see on the day of the shoot. Your responsibility, along with person X and Y, will be to set up launch positions LeftFront1 and LeftFront2, which are shown on pages A, B, and C. Please familiarize yourself with the layouts and the details on the following pages so you have a chance to think about any questions you may have before we meet on the day of the shoot."

Generating Equipment Manifest from Show Design
The site layout and pod details diagrams illustrate the use of the information provided during choreography for purposes other than the choreography itself, i.e., generating the layout diagrams. Though it may be obvious, the diagrams imply an equipment list that is exactly matched to the show.

For designed shows with no mortar angles, one launch position, and no complicated wiring requirements, the calculation of required racks is a rather simple division. However, for more complex shows the calculation of equipment requirements can be tedious and error prone. The wiring constraints necessary to minimize jumping around in the firing sequence may result in unused mortars, for example. The number of mortars in angled racks may not exactly match the number of angled shots, as another example. Generating the equipment manifest automatically in a way that is matched to the show requirements can reduce the chance that the operator will be faced with mismatched inventory on the day of the show, which could result in unsafe improvised changes to the setup.

**Visualizing Safety Distances**

Google Maps and Google Earth are becoming valuable tools for operators and display companies to familiarize themselves with a shoot site before making a site visit, for planning the show, and for generating reports. Even as separate computer tools, Google Maps and Google Earth are already valuable aids. Combined with computer choreography, they become even more valuable.
Figure 2: Rings showing the front launch positions with 3” shells are the constraining factor for audience distance according to NFPA 1123 code of 70ft per shell ID inch.

Once a show is choreographed on computer, the location of the launch positions and the audience can be shown against the site data provided over the network by the Google applications. Rings showing relevant distances around the launch positions can draw upon information about the shell calibers, chains, and mortar angles at each launch position to remind the show planner or operator of considerations that could easily be overlooked if not generated automatically. For example, if the relevant codes (e.g., NFPA 1123) require a minimum 70ft distance from audience per mortar internal diameter inch, and if the minimum distances are doubled in situations in which mortars are set at angles, rings of 420ft radii can be drawn around launch positions with 3” shells shot at angles.

**Experimenting with Wind Effects**

Even strict codes and guidelines cannot replace the need for good human judgment. Unfortunately, human judgment is fallible, particularly when it requires predicting the results of complex physical systems. Shells used in fireworks displays, given their rough, uneven surface, are far from the idealized point masses of high school mechanics, and the results of their interaction with wind can be particularly surprising.

![Figure 3: A choreography program illustrates the effect of wind on the trajectories of the shells, which are notably not the parabolas of high school physics.](image)

Of course, the show planner can't know the direction of the wind at the time of planning the show, but if the show planner can experiment with different wind directions and intensities, and can see the results set against the map of the shoot site, the simulation experience can
provide some background for understanding and communicating the risks inherent in the shoot site.

**Illustrating Effects of Mortar Angle on Fallout**

Perhaps less intuitive than the effects of wind are the effects of mortar angle. Even small mortar angles of 5 or 10 degrees can have a significant effect on the range of shell's trajectory; larger angles can have an astounding effect.

![Figure 4: A choreography program illustrates range differences for shells shot at different angles (straight up, 5 degrees, 15 degrees, 30 degrees, and 45 degrees).](image)

Codes and guidelines may protect against many unsafe conditions, but it is easy to imagine a situation where the operator rearranges the show at the last minute, moving launch positions around the shoot site, and forgets that some mortars are specified as firing at an angle. Reviewing a simulation of the show on computer after making changes can help avoid these mistakes.

**Practicing with Voice Cues**

Electrically fired shows synchronized to music make use of voice cue tracks, which are typically a two channel audio file with one channel containing the music and the other channel containing voice prompts telling the operator when to press the switch to fire the shot. The choreography programs are able to back out the launch times of the shots based on the desired break times and the prefire times of the shells involved.

Typically, electrically fired shows are set up with a consecutive sequence of cues, resulting in voice prompts such as "1..., beep..., 2..., beep..., 3..., beep..., etc." or just "1..., 2..., 3..."
according to the preference of the operator. However there are times when site layouts with multiple launch positions may require jumping around non-consecutively or switching between banks of cues on the firing panel. Since the choreographer may be more concerned about break times while designing the show than launch times, it is possible that a designed show may include launch times that are close together, resulting in a show that is difficult or even impossible to shoot.

Once a show is choreographed on computer, an operator can practice following the voice cues while watching a simulation of the show, or can even practice in a manner that drives the simulation, akin to a video game. Aside from being fun, the practice gives the operator a chance to recognize and prepare for or correct any sections that are too fast. (1)

**QUALITY**

Even though electrically fired shows are not as complicated as computer fired pyromusicals, they can be complicated enough to present order and structure to the audience to the degree that the audience can recognize what could easily be called aesthetic mistakes.

The following sections illustrate a number of such mistakes that can arise in both electrically fired shows and computer fired shows.

**Interfering Tails**

Staring at a script in tabular format, a choreographer can easily overlook a situation in which rising tails attached to larger caliber shells interfere with the visual presentation of a smaller caliber or ground level front that occurs earlier. Looking at the break times, the larger caliber shells may look to be a safely offset in the future, but taking into consideration the longer prefire times of the larger shells, and the time it takes for the front to develop and complete, the situation illustrated in the picture below could easily occur.

![Figure 5: The tails on the large caliber shells interfere with the front even though their breaks occur significantly later in the script.](image)
The fix is simple and obvious: use shells without tails. In fact, both the problem and the fix are obvious. They are the choreography equivalent of a typo—obvious and easy to correct, but only after you notice it.

**Chaos**

A choreographer may shift between simple, orderly firing patterns and more complex arrangements of heterogeneous effects. However, sometimes a complex arrangement can come out looking like a flat-out mess, with no discernable structure or order. For most people, it isn't so easy to predict the difference between a mess and a pleasing arrangement without seeing it. Even for people who are familiar with their product, visual simulation can remove the guesswork.

*Figure 6: The difference between a complex arrangement and a mess is not always so easy to predict.*

**Split Attention**

With a limited field of view, audiences are not able to focus on high aerial shells at the same as low breaking shells or ground work. Choreographers obviously use this human limitation to their advantage as they design aesthetically pleasing stacks that successively raise the audience's attention from flurries of lower breaking shells to higher and higher levels, exceeding the audience's expectations at each step. However the limitation is also a liability, as it is easy to choreograph patterns that are impossible for the audience to focus on all at once, such as illustrated by the following picture.
Figure 7: The audience has a limited field of view--sometimes an advantage, sometimes a liability.

**Trampling**

As illustrated in the picture below, effects that are slow to develop, such as falling leaves shells, are vulnerable to being trampled by other hard breaking shells that interrupt their development. Slow developing, subtle effects may require time to rest even after they are fully dissipated, or they may be perceived as having been trampled. Thus trampling may be possible even if the effects are not technically overlapping.

Figure 8: Slow developing effects like falling leaves are vulnerable to trampling.

**Bad Combinations**

Experienced choreographers who are familiar with their product can develop a sense for combinations that look good together, but for others who are faced with unknown product or who are new to choreography, visual simulation can provide a platform for experimentation to try out combinations and look for effects that are good together, and avoid combinations that interfere destructively.
Figure 9: A chrysanthemum behind a palm may obscure the palm's petals; a peony of the same color as the coconuts may make the coconuts look like errant stars.

OTHER QUALITY CONSIDERATIONS

Aside from pointing out mistakes, computer choreography and visual simulation can help improve the quality of electrically fired shows in positive ways. The following sections illustrate a few of them.

Complementing the Music

There is no way to describe in a set of rules why some patterns of choreography may seem to match the music and others not. Choreography is not just about timing breaks to occur on down beats in the music. At a minimum, choreography involves coming up with a visual presentation that complements the essential character of the music. No rules can capture the nature of this art, and no still picture can illustrate it. But like good opera or dance, you know when you see it.

Making Good Use of Cakes

Single effect cakes and 1.4G PRO products are becoming more common in display choreography. Making good use of them is a challenge for the choreographer. Aside from the visual simulation itself, seeing the duration of the cake in a timeline of the show is the most valuable individual feature for choreographing with cakes. Beyond that, seeing the markings that denote the individual breaks of the cake is useful, though the choreographer must exercise caution as the accuracy of the break times generally degrades as the breaks get further out.
Figure 10: A cake's duration can be shown in a timeline as a horizontal bar, with cross hatches on the breaks of the individual shots.

The figure above illustrates also how a device's prefire time can be represented on a timeline as a bar preceding the first break (at 17 seconds to 19.5 seconds in the figure), and the duration of the effect can be represented as a bar following the last break (from 41.5 seconds to 45.2 seconds in the figure).

Pacing the Display

As choreography shifts between sparse and dense segments, it can be useful for the choreographer to have at hand a visual representation of the visual density of the show over time. The technique of representing a cake's duration and breaks discussed above applies equally well to individual shells. Taken together, all the product in a show can be represented with bars on a timeline that combine as the timeline is compressed to show the pacing of the show.

Figure 11: Overlapping timeline bars representing breaks and durations of effects combine in intensity on a compressed timeline to show the visual density over the course of the display.

A quick glance at the intensity field in the timeline gives the choreographer an indication of what sections may need to be followed by a rest without shooting to give smoke a chance to clear. If choreographing to music, the choreographer can experiment with the relationship between the rests without shooting and the musical accompaniment. Sometimes a rest without shooting is a natural opportunity to let the music have the spotlight for a moment; other times a rest is best with no shooting and no music, giving spectators a moment to process what they just saw.

Reusing and Adapting Previously Choreographed Sections

Not every show needs to be designed from scratch. Reusing sections from previously choreographed shows is a fast way to build a new show, but sometimes the available product doesn't match the product in the cut and pasted sections. Will it look okay anyway?
Choreography programs offer the ability to substitute products, and visual simulation plays the complementary role of showing what the substitutions will look like, removing the guesswork.

PROFIT

The thesis of this paper is that computer choreography can apply to electrically fired shows, and provides benefits in the areas of safety, quality of product, and profit to the display company. Earlier sections have illustrated safety and quality advantages. This section and the next cover economic considerations.

This section on economics covers advantages that apply independently of who does the choreography, the display company or the operators. The next section discusses advantages of enabling operators to choreograph the shows themselves.

Illustrating Benefits of Higher Priced Displays

Visual simulation makes it possible to create sales videos tailored to a particular client. The videos can be set against a background image of the actual proposed shoot site taken using a digital camera or drawn from Google Earth. The videos can be stock example shows, or can incorporate elements suggested by the client, depending on the degree of effort the prospective sale justifies. In a competitive sales environment, customized sales videos can be an advantage. (2)

In addition, the ability to piece together sales videos from predefined sections or make simple modifications without much effort makes it feasible in some circumstances to show a client multiple videos illustrating what they would get if they raise the budget for the show.

Making Sales Meetings Interactive

In larger display companies, the sales team often represents a different part of the organization than the people who do the show design. Sometimes a sales meeting between the sales team and the client generates information about the client's wishes that needs to be brought back to the design team, but since design ideas can be difficult to express, the information carried back may come in the form of notes or sketches on the back of a napkin.

This situation presents the novel idea of equipping the sales team with the choreography software itself, so the sales team can sketch out ideas with the client using the choreography software rather than drawing pictures on napkins. In addition to providing a better form of communication between the client, the sales team, and the design team, the interaction between the sales team and the client may result in a deeper commitment to the sale on the part of the client.
Obviously, equipping the sales team with choreography software is only feasible if the software is easy to use and if the sales team and client can have a positive experience while exploring ideas together. The state of the art in choreography software may not yet have reached that degree of simplicity and ease of use for all people, but as the evolution of graphical interfaces and what-you-see-is-what-you get paradigms have evolved in other fields like word processing, it is only a matter of time for fireworks software tools to evolve to a level that is both easy to use and efficient.

**Using Product More Efficiently**

Earlier discussions in the quality section above illustrate that more product is not always better. The sense of structure and order that choreography can add to a show, even without musical accompaniment, usually results in spacing out the product. Within the context of order and structure, empty spaces of dark sky can be just as important as the dense sections, and light, airy sections can be tasteful complements to the heavy sections. As a consequence, the order and structure provided by even rudimentary choreography in an electrically fired show can result in more efficient use of product, essentially delivering more for less.

Beyond the efficiency that choreography provides naturally, visual simulation gives the show designer the ability to determine the amount of product required to achieve a desired effect. For example, if the designer wants to blanket the sky with willows and hold the effect for a specific duration without ever over-saturating the sky, he can experiment with different numbers of shells, mortar angles, and shot patterns in order to determine the minimum product required.

**Offering Basic Choreography for Musically Accompanied Displays**

Display companies generally charge considerably more for pyromusicals, but are limited on major holidays in the number of pyromusicals that they can put on by their stock of computer firing systems, trained operators, and choreography resources. Within those limitations, offering basic choreography as a higher priced option may present a larger economic opportunity than the big budget pyromusicals. Although lower priced deals, there are just so many more of them. Coupled with sales videos and the potential for interactive sales meetings, basic choreography for electrically fired displays gives the sales team a number of tools to optimize the satisfaction of the customer and the profit for the display company.

**PROFIT BY ENABLING OPERATOR CHOREOGRAPHY**

Besides the finite availability of computer firing systems and trained operators, one of the constraints limiting display companies from offering choreography for more shows is the manpower needed to do the choreography work itself. As long as choreography is limited to
a small team of experienced choreographers on staff or on contract, manpower will continue to cap the opportunity, as the cost of the choreography itself is just too expensive. This section discusses the advantages of enabling the operators to choreograph their shows directly.

**Enhancing Operators' Sense of Ownership**

In one standard work flow, after bidding and planning a show a display company sends a pack list and a cue sheet to the operator, along with a truck full of product and equipment, and the operator then carries out the show according to the cue sheet--at least theoretically. There are stories of operators flat-out ignoring the cue sheet, or changing it on the fly as circumstances in the field may require. Obviously, if the operator is fully decoupled from the client and the show planning process, the operator is in a weakened position to make informed decisions. This may be an acceptable liability for a work flow in which it is not the operator's job to worry about the design of the show, only to execute it. However, it is worth considering the possible advantages of allowing the operator to take a more active role in the choreography of the show, if an adjustment to the work flow can continue to provide the display company with the necessary control and oversight.

Of particular interest are the cases of electrically fired shows on major holidays, with or without musical accompaniment, that could benefit from basic choreography if the resources were available. For these cases, involving the operator in the choreography has the potential to solve the resource problem, better prepare the operator for decisions on the field, and enhance the operator's sense of ownership over the end product, resulting in higher quality displays for the client.

A possible work flow that incorporates operator choreography while maintaining the display company's control and oversight is one that allows the operator to do the basic choreography from the set of specifications agreed to by the client and the sales team, such as a defined musical sound track, an expected show duration, and a quota of shells for each caliber. The specifications could also include specific requests of the client, which could be added as notes or provided as actual choreography sections as discussed above in "Making Sales Meetings Interactive."
While pinning down the basic parameters, these specifications still leave the operator plenty of room for choreography.

Assuming the specifications allow the operator to choose the product, there is advantage in integrating the operator's choreography system with the inventory management systems of the display company, thereby allowing the operator to pick from the display company's available product.

Obviously information such as the cost of product is private to the display company, but even without that information the product list and quantities can be made available to the operator to ensure the product he selects is at hand. The display company can actually exercise an arbitrary degree of control, from setting quotas per caliber all the way to specifying all the product as in the original work flow. The operator can submit his completed choreography to the display company for approval, after which the required product can shift status in the inventory management system from available to allocated, or whatever equivalent terms the display company uses.

Whatever degree of freedom the display company chooses to allow, the operator has plenty of flexibility to provide meaningful basic choreography for an electrically fired show, and in so doing solve the choreography resource problem while providing the increased sense of ownership and other benefits.

**CONCLUSIONS**

This paper challenges the assumption that computer choreography and visual simulation apply only to computer fired shows. A number of advantages of computer choreography for electrically fired shows have been presented in the areas of safety, quality, and profit. Sales methodologies in which computer choreography plays a greater role in the interaction with the client have been discussed and extended to a model in which operators play a greater role in providing basic choreography for electrically fired shows.
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Ideas for improving display quality with choreography encapsulate general principles known among choreographers, but have been presented here in the specific light of visual simulation. In articulating these principles I am indebted to Aaron Mayfield and John Sagaria for their perspicuous presentations at the 2010 WPA (3) and 2010 PGI (4) conventions, respectively. Thank you, gentlemen.

REFERENCES

(1) The choreographer may change a complex section to make it shootable with voice cues, or may use of chains or time delays to thin out the voice cue requirements to achieve the same effect.

(2) Even if the sales team has the complete show at hand, making a video of parts of the show, akin to a movie trailer, may be more effective at selling the show, and may also avoid the liability of a later claim that the actual show didn't exactly match what was promised.
