On and Beyond the Edge

Visual Stories of Winning Margins in Elite Sports

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Submitted in partial fulfillment of the requirements for the degree of
Master of Science in Data Visualization at Parsons School of Design

May 2018

With gratitude to Catalina

SUMMARY

Olympic Games and World Championships showcase the world's elite athletes. While medalists earn a significant premium over fourth place finishers, the margins of victory have become vanishingly small. To surmount these margins, athletes are continuously acquiring sources of advantage, from training to nutrition and equipment, and, in some cases, illicit performance-enhancing substances. The trio of interactive visualizations at https://julianhlange.github.io/thesis examines three stories from and beyond the edge of victory. First, situated in the 2018 Winter Olympic Games, users are invited to test hypothetical scenarios in which athletes' performances improve by small increments, from 0.05% to 1%. The second visualization highlights a story from the swimming pool, where advances in swimsuit design effectively changed the parameters of a sport. Finally, users can re-live the 2018 Winter Olympic Games men's singles luge event, which was won by 0.028 seconds, via an animation that displays the top eight athletes head-to-head.

INTRODUCTION

In the late afternoon of September 29th, 1988, as a light wind was blowing down the track at Seoul Olympic Stadium, eight elite sprinters lined up in the starting blocks for the women's 200-meters final of the 1988 Summer Olympic Games in South Korea. Florence Griffith Joyner of the United States was considered the favorite for the gold medal. In the semi-finals earlier that day, she had beaten the previous world record of 21.71 seconds by 15 hundredths of a second. In the final she would be competing against the other seven best sprinters in the world, including Heike Drechsler, who had jointly held the world record with another East German until Griffith Joyner broke it in the semi-finals. As expected, Griffith Joyner won the final handily. Surprisingly, however, she shaved an additional 22 hundredths of a second off the world record, finishing 38 hundredths of a second ahead of the silver medalist. Thirty years later, her winning time of 21.34 seconds still stands as a world record, and no athlete has come within 28 hundredths of a second of that time.

Olympic athletes are celebrated for the physical strength, speed, and endurance of their bodies and the psychological fortitude of their minds. Available to the best among them—Olympic medalists, in particular—are large financial rewards through direct compensation structures as well as endorsement opportunities. Thus, athletes and the national sporting federations that support them employ a wide range of methods to optimize performance, including advantages gained from nutrition, equipment, training methods, and technology. Unfortunately, the pressure to win and the promise of accompanying commercial success lure some athletes and their national teams to engage in illicit performance-enhancement measures such as blood doping. Within the scope of legal performance-enhancing measures lie sport-specific technological advances that, while not inherently illegal, provide significant advantages to those who have access to them. The overarching athletic goal of all of these tactics is to overcome the margin required to become a winner—to make it to the edge of victory.

The interactive visualizations described in this thesis examine the concept of edge in elite sports. They ask the following questions. First, across a wide array of Winter Olympic sports and disciplines, what are the differences between first-place finishers and the rest of the field and what relative advantages are needed to make the leap from 'just' an Olympian to Olympic medalist? Second, how did a technological advance in swimsuit design in 2009 enable swimmers wearing a specific suit to go beyond the edge and break world records in unprecedented numbers? And finally, can an animation of an event from the 2018 Winter Olympic Games capture the thin margin of victory and defeat?

PART 1 – THIN MARGINS OF VICTORY AT THE 2018 WINTER OLYMPIC GAMES

For many elite athletes, qualifying for the Olympic Games is in and of itself the primary goal of their athletic careers. Indeed, the vast majority of Olympians who participated in the 2018 Winter Olympic Games in PyeongChang, South Korea, did not win a medal. However, for a small fraction of athletes, their true measure of success is determined by medals won. Given these differences in ambition, what are the differences in athletic abilities between medal winners and non-medalists or even between gold medalists and silver medalists?

To get a general sense of the winning margins in one Winter Olympic sport, let's look at the 2017–2018 World Cup luge men's singles season, which comprised nine races of 'classic' length and four 'sprint' races. Winning margins in the classic length ranged from 0.011 seconds to 0.386 seconds after ~85–109 seconds of racing. Each luge track has different characteristics (length, shape, temperature), so time differences between races are not directly comparable. However, if race times are converted to performance relative to first place (see below), then results across races can be compared. For the 2017–2018 World Cup luge men's singles season (classic length races only), these margins translated to a range of performance differences between first and second place of 0.01–0.43%. Two thirds of the races were won by a performance difference of less than 0.1%. This finding indicates that even seemingly meager improvements in speed—through form, strength, technique, and other performance-enhancing methods—are likely to provide an athlete with a significant improvement in race placement.

What do the margins of victory look like across a wide range of sports at the 2018 Winter Olympic Games? What level of improvement would have been required of non-medalists wishing to become medalists? Silver to become gold? To assess these questions, I created an interactive visualization for users to examine hypothetical scenarios in which the performances of subsets of athletes are improved by small increments.

Criteria for inclusion of sports in visualization

The premise of the visualization is predicated on comparisons of maximum athletic performance. Only sporting disciplines in which the participating athletes have produced the best possible performances and in which athletes could be expected to have exerted maximum physical effort while minimally taking into account the efforts of their competitors were considered. Thus, in order for a sporting discipline to be considered, it had to meet the following two criteria:

1. Time was the only measure of athletic performance. Sports that were wholly or partly judged (e.g., figure skating), comprised more than one competence (e.g., Nordic combined), or based on a scoring system (e.g., ski jumping) were excluded.
2. The event discipline was conducted as a time trial, such that athletes were not competing head-to-head. There are two reasons for this criterion. First, athletes sharing a course may use opportunities to draft behind their competitors. Second, athletes on the course at the same time may gauge their competitors' performance and modify their own performance (e.g., mass start events in cross country skiing). For example, athletes may slow down if they have secured a winning lead well before the finish line, which would have the effect of reducing differences in performance.

Based on these criteria, the following events were included in the visualization:

1. Alpine Skiing: men's and ladies' downhill, super-G, giant slalom, slalom, and combined
2. Bobsleigh: two-man, four-man, two-woman
3. Cross Country Skiing: men's 15 kilometers, ladies' 10 kilometers
4. Luge: men's singles, men's doubles, ladies' singles
5. Skeleton: men's singles, ladies' singles
6. Speed Skating: men's 500 meters, 1000 meters, 1500 meters, 5000 meters, 10000 meters; ladies' 500 meters, 1000 meters, 1500 meters, 3000 meters, 5000 meters

Assumptions

The criteria above narrow the wide range of sports disciplines down to a handful of events that can be interrogated. However, because the discussion assumes that the performances in a race are representative of the spread in elite capability for that sport, the premise of the visualization rests on additional assumptions. The reason for these assumptions is to be conservative about the causes of the spread in differences, so that all differences represent precisely the maximum capabilities of the athletes in each race. The following assumptions essentially derive from some of the same principles upon which the criteria for inclusion are based.

1. In each race, the world's best athletes were competing. If not, then one would expect to observe greater differences.
2. The athletes were maximally prepared. Given the prestige of the Olympics, athletes were expected to focus their preparation around these events.
3. All athletes were exerting maximum effort. If not, then the observed difference between, for example, first and second place might be larger than the actual difference in capability.
4. Athletes were not using information about their competitors' performances to calibrate their own performances. Even among the sports that remained after filtering by criteria, in some disciplines information about other athletes' performances may have been available during an event. For example, in the women's 10-kilometer and men's 15-kilometer cross country skiing events, skiers starting later had access to information about competitors with earlier start times.

Data acquisition, processing, and visualization

For each sport and discipline, competition data were acquired from the PyeongChang 2018 website of the International Olympic Committee.[1] I downloaded PDFs, converted them to CSV-formatted plain text using an online tool,[2] and scraped and tabulated relevant data using R version 3.3.3.[3] Final tables were compared with original data to confirm accurate processing.

For each event in the visualization, the top eight finishers were included. The finishing time of each athlete was converted to a measure of performance relative to the first-place finisher. For example, in the alpine skiing men's slalom event, the gold medalist Andre Myhrer completed the race in a time of 1:38.99 and the silver medalist Ramon Zenhaeusern in a time of 1:39.33. With Myhrer's performance set to 100%, Zenhaeusern's performance was calculated to be 99.66%. This arithmetic effectively converted relative performances into a percentage of first place speed.

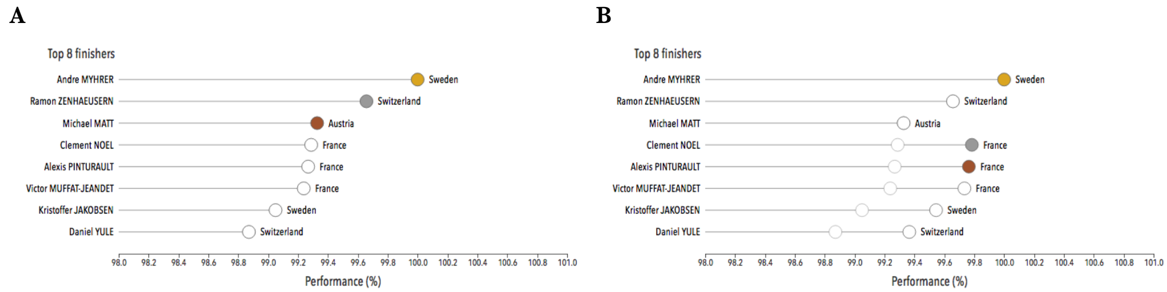

Figure 1. In the 2018 Winter Olympic Games men's alpine skiing slalom race, a 0.5% improvement in performance by all non-medalists would have changed the medal standings

A. Actual standings and relative performances of the top eight finishers. B. In a hypothetical scenario in which the non-medalists improved their performance by 0.5%, the gold medal would still have been won by Andre Myhrer of Sweden. However, the silver and bronze medals would have been awarded to Clement Noel and Alexis Pinturault of France. In panel B, greyed out circles depict the actual standings. Users also have the option of clicking on each athlete's name to be directed to the website corresponding to the top Google search result.

Users on the website select sport and discipline from dropdown menus. In a first view (Figure 1A), the actual results of the top eight finishers for the selected event are shown using the performance scale described above. Users are then invited to test different scenarios in which the performances of subsets of the eight athletes—either all competitors except the gold medalist or all non-medalists—are improved incrementally by 0.05%, 0.1%, 0.2%, 0.5%, or 1%. Users select the subset and increment with radio buttons. The data underlying the transformed values were calculated in R. The resulting visualization (Figure 1B) displays how the event's standings would have changed under the user-selected scenario. The visualization was implemented using JavaScript and the D3.js library. See the key of Figure 1 for additional features.

A cursory analysis indicates that, under scenarios of all non-medalists improving by 1%, every event analyzed would have experienced different medalists. Remarkably, changes as small as 0.05% would have affected finishing standings in several events, including disciplines in alpine skiing, bobsleigh, luge, skeleton, and speed skating.

PART 2 – CHANGING THE PARAMETERS OF A SPORT: AN ARMS RACE IN SWIMSUIT DEVELOPMENT

A major draw of elite sports is the spectacle of breaking a world record. Record holders are celebrated as the strongest, the fastest, the most skilled—'the best ever,' given the available methods and know-how at the prevailing moment in time. However, the marriage between sports and technology has changed the opportunities for breaking records. As Tara Magdalinski writes in *Sport, Technology and the Body: The Nature of Performance*,[4] "the conflicted relationship between sport and technology is far more complex than casual analyses might suggest, and it would certainly be naïve to regard, or even to prefer, sport and technology to be independent categories with little overlap." Indeed, in this current age of data, we have accepted the incursion of data into sports and we have recognized its essential role in maximizing human athletic ability.

This leads to several questions about our vision of 'the best ever.' How do we incorporate the fraction that is strength or speed or form and the fraction that is technology-driven? In the technology-driven fraction, might we be able to distinguish, on one hand, the data-driven improvements in training methods that optimize the body's athletic potential, from, on the other hand, material improvements in equipment that essentially change a sport? What does a record in a sporting event signify in the long-term if the parameters defining that sport evolve? In this section, I created a visualization to accompany the written case for greater vigilance in monitoring the impact of technology-driven advances in a sport.

Competitive swimsuit development underwent major changes in the first decade of the 21st century.[5] The most egregious example led to drastic rule changes that banned a synthetic material that, in 2009, had felled many prior world records. The following story exemplifies how advantages afforded by technology can effectively alter the definition of a sport across eras. An accompanying visualization conveys how swim times in 2009 were a function of swimsuit materials.

Evolution of competitive swimwear: 1999–2010

In 1999, the Australian swimwear manufacturer Speedo introduced the Fastskin swimsuit. It was designed to simulate shark skin dynamics by incorporating strategically placed ridging to create low-pressure zones that ostensibly optimized water flow around a swimmer's body.[5] Furthermore, it left only the hands, feet, head and neck uncovered, as Speedo—and other swimwear manufacturers—had recognized that full-body cuts offered dramatic reductions in hydrodynamic drag. Thus, by the time of the 2000 Summer Olympic Games in Sydney, Australia, many athletes were competing in Speedo Fastskin swimsuits or similar full-body suits by other manufacturers. Fourteen world records were broken during the Games. Although the effectiveness of the shark-skin-like ridging was later called into question,[6] the full-length body suits had catapulted swimming performances forward. At the 2004 Summer Olympic Games in Athens, Greece, swimmers were competing in the next-generation Fastskin II suits.

At the 2008 Summer Olympic Games in Beijing, the Fastskin line was superseded by Speedo's LZR Racer swimsuit. Whereas previous suits had been composed entirely of synthetic textiles—nylon and lycra—the LZR Racer swimsuit incorporated polyurethane, a non-textile material.[5] The parts of the suits coated with polyurethane were impermeable, thereby exposing less of the athletes' skin to the water. Furthermore, the swimsuit acted as a sort of aquatic corset, compressing swimmers into a more hydrodynamic shape that reduced drag by facilitating maintenance of optimal body position. The swimsuit's reduced overall permeability also trapped tiny pockets of air between the material and the swimmer's skin, thereby increasing buoyancy. With a larger fraction of the body above water, drag was dramatically reduced. The combined effects on permeability, buoyancy, and hydrodynamics rendered this suit incomparable with any of its predecessors. Indeed, 94% of all gold medals awarded in swimming at the 2008 Summer Olympic Games were won by athletes in the Speedo LZR Racer.[7,8]

In the wake of the dominance of the LZR Racer swimsuit at the 2008 Olympics, Speedo's competitors were compelled to design the next generation of suits. In 2009, the brand Arena unveiled the Arena X-Glide, a pure-polyurethane suit that was fully impermeable and further reduced hydrodynamic drag. At the 2009 World Championships in Rome, where several athletes were using this latest technology in swimsuits by Arena, Jaked, and Adidas, an astonishing 43 world records were set; of these, 37 were set in pure-polyurethane suits.[9] Several swimmers, including some who had benefited from the Speedo LZR Racer in 2008 and who, bound by contractual obligations, were not allowed to swim in other brands, expressed unfairness.[10]

The spotlight on swimsuits during the 2009 World Championships spurred the Fédération Internationale de Natation (FINA), the governing body of elite swimming, to issue new rules for swimsuit design.[11] Specifically, full-body suits were no longer permitted and materials were only to be textile fabrics that met specific guidelines on buoyancy and permeability.

The full-body cuts and polyurethane materials of the LZR Racer of 2008 and Arena X-Glide of 2009 were banned effective January 1, 2010. Notably, however, the world records from 2008 and 2009 were allowed to stand, and many still do to this day.

Making the case with a visualization

How did developments in swimsuit technology change the sport of swimming, at least temporarily? A 2012 study[12] by Foster and colleagues estimated the gains provided by each of the three major advances in swimsuit technology. Using men's freestyle results from 1948 to 2009 in a regression model, the authors calculated a 0.9–1.4% increase in performance due to the full-body swimsuits of 2000, a 1.5–3.5% increase as a result of the polyurethane-paneled suits of 2008, and up to a 5.5% increase provided by the pure-polyurethane suits of 2009.

To look at the most egregious example—the pure-polyurethane suits of 2009—a visualization of races at World Championships between 2003 and 2017 shows these suits to be outliers (Figure 2). World Championships are held biennially, so a visualization should reveal any clear patterns. To this end, I created a visualization of the actual swim times of all 50-meter and 100-meter men's and women's event finals (but not preliminary heats or semi-final races) from World Championships between 2003 and 2017. Data were publicly available on the websites of FINA[13] and OMEGA Timing,[14] the official timekeeper of FINA races. In all but two races, times were available for all eight athletes who competed; in each of the remaining two races, one athlete was disqualified from the competition and no time was recorded. The visualization was implemented using JavaScript and the D3.js library. See the key of Figure 2 for additional features.

If the pure-polyurethane swimsuits did provide a substantial advantage, then swim times should have vastly improved between 2007, when the suits were not in use, and 2009. Furthermore, swim times should have worsened in 2011, the first World Championships held after the ban went into effect. Indeed, this pattern was observed in all 16 disciplines examined (Figure 2). Swim times improved gradually between 2003 and 2007, then improved markedly in 2009. After full-body suits and polyurethane materials were banned in 2010, swim times were much slower in 2011. Between 2011 and 2017, the rates of improvement in swim times were more consistent with those of the early 2000s. The visualization shows clearly that, irrespective of gender, distance, and stroke, winning swim times and median swim times improved between 2007 and 2009, then slowed down between 2009 and 2011.

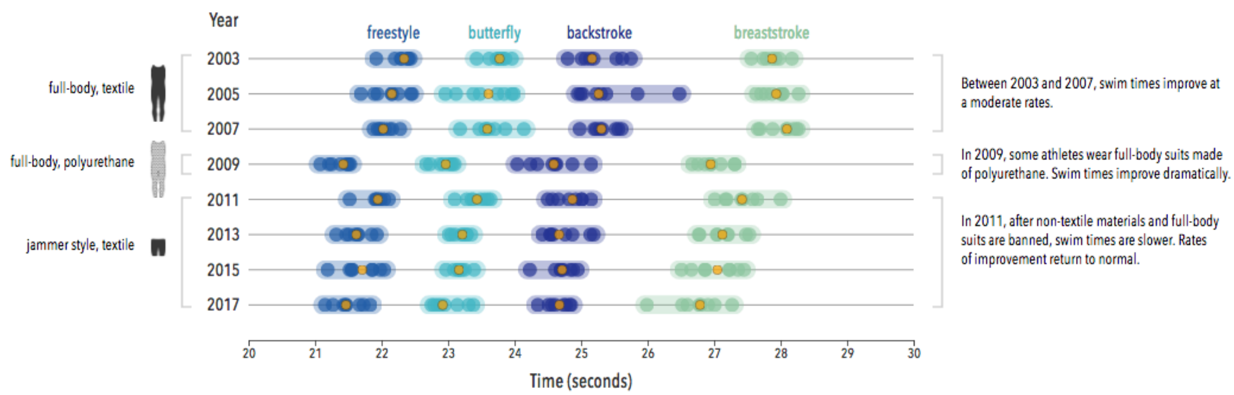

Figure 2. Swim times in freestyle, butterfly, backstroke, and breaststroke in men's 50-meter events at World Championships 2003–2017

Across all four strokes, swim times improved gradually from 2003 to 2007, improved substantially at the 2009 World Championships, then worsened at the 2011 World Championships before improving at gradual rates again through 2017. Circles along a horizontal line correspond to swim times in the World Championship of that year. Each pod of eight circles (grouped by light shading) denotes the finishing times in an event final. Orange circles denote median swim times in event finals. Other features of the interactive visualization include athlete name, swim time, and rank upon hover over any circle, as well as the option of clicking on any athlete's name to be directed to the website corresponding to the top Google search result.

Lessons

The alarms bells rung in 2009 and precipitated by an unseemly number of broken world records were loud because the advances in swimsuit technology were deemed an unfair advantage in the technological arms race. It should be noted that such advances had been made for a decade. These findings raise questions about the significance of world records in a sport where materials have altered performances so dramatically.

A recent systematic review[15] of peer-reviewed literature identified numerous sports that have been impacted by the implementation of new technology. In some cases, such as the introduction to tennis, cricket, rugby, and volleyball of 'Hawk-Eye' technology that aids line judging by gauging likely ball trajectory, the advances acted predominantly to favor a notion of competitive fairness rather than to increase individual performance. However, in other cases, such as the mid-20th century innovation of fiberglass poles in the pole vault or the adoption of 'clap skates' by speed skating in the 1990s,[16,17] such revolutionary changes subsequently hampered straightforward longitudinal comparisons of performances. In a 2012 study,[18] Balmer and colleagues used non-linear regression to model the progressive plateauing of athletic performances over time. By using such statistical methods on historical data from four Olympic track-and-field jumping events, the authors were able to characterize the impact of major innovations. The pole vault, with its technological change in pole material, and the high jump, with its revolutionary change in technique (the 'Fosbury Flop', introduced at the 1968 Summer Olympic Games in Mexico City), benefited from the application of a double logistic regression model of growth, which could account for the innovations in a way that single logistic regression model of growth did not. This contrasted with the long jump and triple jump, which had not undergone major innovations in technique or technology and could be modeled effectively with single logistic regression. Similar statistical methods can be used to consistently evaluate the progression of sporting events and potentially to uncover outliers in the evolution of sporting results. The application of visualization techniques helps researchers and non-experts alike appreciate how such advances impact a sport.

PART 3 – ANIMATION OF THE 2018 WINTER OLYMPIC GAMES MEN'S SINGLES LUGE EVENT

Luge is a winter sliding sport in which one athlete, or a two-person team of athletes, lies face up on a racing sled and steers the sled down an ice track. It has been part of the Winter Olympic program since 1964. The highest level of international competition is governed by the Fédération Internationale de Luge de Course (FIL) and is carried out on artificially constructed tracks. At the Olympics, each athlete in a singles competition completes four runs of the track. The aggregate time of the four runs is determined to the thousandth of a second, and the athlete with the shortest overall time is declared the winner.

For the purposes of assessing the provisional standings of competitors while they are on the course, timing wands are placed at several positions along the track. At the 2018 Winter Olympic Games in PyeongChang, such 'split times' were measured at four locations along the track as well as at the finish line. Thus, a viewer watching the competition could get a sense of provisional standings at each split time position and at the finish line, for each of the four runs. This enabled viewers to assess each athlete's performance during a run. For example, a steering error that brought a sled into contact with a wall would show up in a subsequent split time comparison.

In PyeongChang, the men's singles competition was held on February 10–11, 2018, with two runs on each day. Forty athletes competed, each completing either three or four runs of around 47–50 seconds per run. Thus, spread over two days, there were roughly two hours of actual racing.

Objective of the animation

In creating a visualization of the men's singles competition, I wanted to meet two main objectives. First, I wanted to shorten the time taken to view the competition, from two hours spread over two days down to less than one minute. Second, I wanted to display the results in a way that viewers could observe how close the racers were at any time and could determine where the athletes made up or lost ground on their competitors. To meet these objectives, I used published data from the race to create an animated representation of the top eight finishers competing head-to-head on a track.

From data to design to visualization

Split times, finishing times, and velocities at each split position were publicly availably on the 2018 Winter Olympic Games website.[1] Timing wand positioning was provided through personal communication with FIL. Distance measurements were converted to meters, time measurements to seconds, and velocities to meters per second. Because times and velocities were only available at the split points, calculations were based on the assumption of constant acceleration (or deceleration) in any interval. (Due to the serpentine nature of luge courses, acceleration is almost certainly not constant in any interval.) In addition, because velocities accompanying the first split position were not measured, I did not incorporate the first split time value for each run into the animation.

In order to model position along the track at any time t_i for each athlete, I used the following standard physics equations relating velocity, time, and acceleration:

$$x_i = x_0 + v_0\, t_i + ½\, a\, t_i^2$$

where, at any time t_i:

x_i	=	position along the track at time t_i
x_0	=	start position
v_0	=	velocity at start position
a	=	acceleration

First, for each interval, under the assumption of constant acceleration or deceleration a, one can extract a as follows:

$$a = \frac{x_f - x_0 - v_0\, t_f}{½\, t_f^2}$$

where:

x_f	=	end position of interval
x_0	=	start position of interval
v_0	=	velocity at start position
t_f	=	time to complete interval

Then, to calculate position x_i along any interval at each hundredth of a millisecond t_i, I integrated the extracted acceleration formula into the original equation. Thus, for each interval:

$$x_i = x_0 + v_0\, t_i + ½\, \frac{x_f - x_0 - v_0\, t_f}{½\, t_f^2}\, t_i^2$$

where, at any time t_i:

x_i	=	position along the track at time t_i
x_0	=	start position of interval
v_0	=	velocity at start position
x_f	=	end position of interval
t_f	=	time to complete interval

Using this last equation, I created a vector of values for each athlete, where each value i in the vector corresponded to the position x_i calculated at each one hundredth of a millisecond t_i. Anticipating an animation frame rate of 60 frames per second, I then extracted the values from the vector that corresponded to each one 60th of a second of actual racing. Finally, in order to speed up the animation five-fold, I retained only each fifth value. Thus, in the animation, each frame represents one 12th of a second of actual racing. The calculations were performed in R.

I designed and implemented the animation with the p5.js library. Symbols denoting each of the athletes move according to their calculated positions during the race. Additional features, such as lines denoting split positions and the names of the athletes, were included to provide context for the race. All elements, including the components that make up each national flag, are p5.js shapes placed and translated by frame.

CONCLUDING REMARKS

The 1988 Seoul Olympics women's 200-meter race was remarkable not only because of the world record time, but also because Florence Griffith Joyner shattered the previous record by 1.7%. Over the course of a single day, Griffith Joyner had taken 37 hundredths of a second off the world record—roughly the blink of an eye, but an eternity in elite sprinting. Notably, in her 100-meter results two months earlier that year, she lowered the world record by 2.5%. These athletic performances were outliers in sprinting history. Perhaps not surprisingly, Griffith Joyner was suspected of employing an illicit source of edge: performance-enhancing drugs.

The interactive stories visualized in this thesis demonstrate why the numbers 1.7% and 2.5% stand out: margins of victory at elite levels are generally much thinner. Data visualization has the power to tell stories with data and thereby convey in unique and compelling ways the extraordinary drama playing out at the top of elite sports.

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