THE ART AND
TECHNIQUE OF
MATCHMOVING
Solutions for the VFX Artist

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Dedication

To my parents, without whom this whole darn wacky adventure never would’ve gotten off the ground.
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I *would* thank my cat Harper, but she’s been nothing but trouble and is driving me nuts. As I write this, she’s curled up next to me, asleep and adorable. Thanks, Harper!
Foreword

Just a couple of days ago, a college friend of mine shared a link demonstrating the use of some new digital Canon camera backs in place of Panavision film rigs for shooting driving plates on the television show 24, with the comment that the “producers of the show are all too happy moving to Canon equipment, away from Panavision. Panny’s long hold on the motion picture biz may be slipping as tech goes increasingly digital, allowing other camera [manufacturers] a chance at the trough. Cheapest, most reliable solution wins.”

Before I wrote this book, I would have laughed. In my entire film – and television, for that matter – career, I’ve worked only with material originally shot on 35 mm film. Sure, in TV it’s converted to video and has 3:2 pulldown and all that stuff, but it still originated on Kodak stock.

Occasionally I’ve gotten some weird one-off plate shot on a digital still camera for use in modeling a chair or something like that, but never, until this book and a job I had about a month ago, have I ever done a real shot with plates originating in a digital format.

Let me tell you something: I’ve been really spoiled. As of this writing, I’ve found that there aren’t really hard and fast standards for video filmbacks. As you’ll see in later chapters, there isn’t really any standardized way to record a focal length when shooting with a digital camera, as there is in 35mm film photography. There is still quite a bit of confusion as to how exactly the image is captured on a digital chip; often, I found, much to my surprise, the images are squeezed – a situation less than desirable for matchmoving purposes.

Video plates take some getting used to, let’s just say. Take the Canon example I just mentioned. The chips in the cameras mentioned are almost – but not quite – the same size, in inches, as a VistaVision plate, a very large film format used mostly for VFX work. Every piece of matchmove software has a preset for Vista – useless for this camera. It’s just not the same size. So, will there be a new preset for that particular camera? Or will the camera manufacturers adapt? We shall see, but for now, we matchmovers are reduced to doing actual math.

The DPs in the clip go on to talk about the possibility of new prime lenses for their purposes – but what will they be? The difference in the chip size messes around with the relationship of the lens to the image (technical term). Now what?

It’s a brave new digital world, and somehow I didn’t notice, even though I do everything on an iPhone named – you guessed it – JackBauer.

I do not know Jack’s chip size.
In the end, new standards for chip sizes will be agreed to, and new software will come with presets for whichever digital cameras win the battle for filmmaking supremacy over the next few years. It’s an interesting time, actually, similar to the early years of motion pictures and all the different film gauges and formats that eventually evolved into the handful of standard formats we have today.

Until then, we matchmovers will just have to think a little harder about what we’re doing when we set up a camera. Because everything else, from files crashing Maya to character animator’s work getting deleted, two days of rain in a row, and who knows what else is matchmove’s fault anyway, why not throw the evolution of an entire new generation of standards and practices in there too? We can handle it. This. Is. MATCHMOVE!

Los Angeles, February 2010
INTRODUCTION: WHAT IS MATCHMOVE, ANYWAY?

“So, Wait a Minute . . . . What Do You Do, Exactly?”

Don’t feel badly if you’re asking this question even as you’ve picked up this book. I was at a work party just a few months ago, at a well-respected, Oscar-winning visual effects house, and was asked that same question—by a character animator!

Whether you call it camera tracking, camera matching, or any other name, matchmove is definitely a mystery to most people—even some of the people you’ll work for. Even I didn’t know what it was when I took a course in it some years ago. Part of the reason for this is that if done right, you’ll never notice a matchmove . . . you’ll only see it when it’s badly done.

So what is matchmove? In a nutshell, the matchmover takes information from a real-life set, where the actors, director, and all the other crew members who make movies shoot a film, and recreates that camera, including the focal length of the lens, the height, the tilt, and the position and motion relative to the virtual set and characters at the beginning of the shot.

Figure 1 The virtual camera is lined up with the virtual set and characters at the beginning of the shot . . .

Camera Tracking

The process of recreating a live camera move in the virtual CG (computer-generated) world. Often used interchangeably with matchmove, though the former implies the use of automated software and the latter implies a more hands-on approach.

Camera Tracking Software

Software developed specifically to derive 3D information from 2D plates, using the relative motion in the plate as the basis for solving the resulting camera move.

Rendering

The process of “photographing” the CG environment and creating 2D images to use for integration into the live action plate. Think of filming a scene and getting your film developed in one step.
the subject, in the CG environment. Then, when the CG world is created, it is “photographed,” or rendered, with the virtual CG twin of the real-life camera: the same lens, the same position,
and the same movement, if there was any. In that way, the CG elements created in the virtual world will have the same perspective, the same depth, and the same relationships to the moving camera that the live actors and set pieces had to the live camera, allowing them to be seamlessly integrated into the live plate for the final shot.

After **3D camera solutions** have been created and approved, there are other elements that might need to be matched. If a full CG character interacts with a live actor, for example, a CG representation of that actor, or **CG puppet**, will need to be added to the virtual scene and its movements animated to match the live actor’s movements. Or perhaps **CG effects** will be applied to a real-life actor — maybe he is covered with living goo, for example. In some cases, heads, arms, or other parts of the body may be replaced with CG elements; a very close match of the actor will be needed for the CG elements to blend seamlessly with the live action plate. Animated CG puppets are also needed to cast shadows and reflections on CG elements added into a scene.

As you can see, this can become quite involved! How does it get all done?

There are several **automated camera solvers** available on the market, such as Maya Live and MatchMover2010, Boujou, and PF Track, which can be an enormous help in a production of any size. Many facilities also have proprietary software used for matchmove tasks. Frequently, however, automated solvers don’t get the entire job done: a camera solution from the solver can be close but not dead on, or the automated solver might not be able to solve the camera move at all. Many times, though, an automated solve can get you 80% to 90% of the way there.

In order to get that last 10–20%, it’s crucial to be familiar with all the aspects of matchmoving, from the technical functions of a camera, to on-set data collection and the manipulation of that data in the virtual environment. In addition, a matchmover has to be **creative**. He or she should know how to attack a shot when little or no information is available from set. He or she should be familiar enough with lenses and cameras to be able to spot mistakes in the data from set and account for them. He or she should be able to do some detective work, and to use **all** the tools at his or her disposal, including researching on the Internet. Most of all, a matchmover needs to use good old **common sense**. A camera solution from an automated system might look okay when seen from the camera view, but a good matchmover knows how to make sure the solution is good from **all angles**. In other words, a matchmover must constantly ask him- or herself, “Can a camera really do that?” It’s common
sense, when added to the rest of the knowledge and information at the matchmover's disposal, that makes the difference in any situation.

With this book, I hope to instill not only the technical skills necessary for successful manual matchmoving, but to also foster the curious, creative spirit that makes a hopeless-looking matchmove a successful one. I’ve included tips and tricks for seemingly impossible matchmove situations, from scouring the Internet for photographs of an actor's hands so that an accurate model can be built to using basic architectural knowledge in creating a quick virtual set. A creative matchmover, using common sense, can't be beat, and I hope to show you how to think outside the matchmove box.
What Does a Typical Matchmove Task Look Like in the First Place?

Before we go any further, you’d probably like a basic understanding of what exactly goes on in the matchmoving process, right? You saw a very basic illustration of the CG environment in the introduction, but how does all that information get into the computer, and then what the heck do you do with it?

In the very big scheme of things, the matchmoving process goes like this:

- Planning
- Gathering data on set
- Building assets
- Reviewing data
- Attacking the shot
- Passing the shot on to other artists

We’ll also look at:

- How the computer thinks about all of this stuff

Planning

The first step in the ideal matchmove process is planning, well before any filming ever occurs. The matchmover going to set will read the script, look at concept art and preproduction digital tests (called “Look Dev”), and generally familiarize him- or herself with the information needed to recreate the locations, props, and cameras in the CG environment back at the office after filming. With a plan in hand, the matchmover goes to location.
Gathering Data

On location, a variety of tools, from a simple sketchbook and measuring tape to advanced equipment like laser-equipped survey heads and LIDAR, are used to survey the location so that it can be recreated in the CG environment later on. The on-set team takes detailed measurements of the location or set, the buildings, furniture, trees, landscape features, light poles, chairs, cars, dishes, carpets — basically, anything that can be measured and holds still long enough to be measured, the on-set matchmove team will try to measure or otherwise document its shape, size, and any distinguishing details that might help in camera tracking back at the office, just as any site surveyor would. They’ll try to photograph everything possible on location for reference later. They’ll record details about the camera for every take — the lens, the focal length, the focus distance, distance to subject, height, tilt, roll, and anything else that can possibly be written down in the time there is. Basically, they try to get any and all information necessary to build a replica of the real-life

Figure 1-1 Shooting on set.
set in the computer back at the office. The more detail recorded, the better.

At the same time, if the effects in the show require this level of detail, the actors are being scanned in 3D so that the show will have accurate character models to work with in the CG environment.

### Building Assets

When the on-set team gets back to the office, all the information, measurements, survey data, LIDAR data, photographs,
Character Models

Digital models used specifically to animate people and other characters. These are set up by the riggers to be animated with an articulated digital skeleton.

Skeleton

An articulated structure created mimicking the bones and joints of a human or other creature and attached to a virtual “skin,” allowing it to be animated the way humans and other creatures move.

Prop

Short for “property.” On set, props are anything actors can easily move around and interact with. These are usually then recreated in the CG environment by the modeling department, though occasionally a matchmover creates his or her own props.

Practical

The real-life prop, makeup effect, special effect, or other on-set, live-action element to be duplicated or extended in CG. If it’s in the plate, it’s a practical. I’ve been known to accidentally refer to an actor or two as “the practical guy” on a few occasions!

and other notes are assembled and disseminated to the rest of the facility. The modeling department creates digital models of the sets, locations, and characters. The character models are given animatable skeletons by the rigging department. Notes, camera details, photos, and anything else brought back from location are organized and made available by production staff. Then the fun starts!

Attacking the Shot

This is the beginning of the actual digital portion of matchmoving. Notice how much work is done before any matchmove-specific software is even touched!

After reviewing all the data from set, the matchmover creates a virtual camera based on this data. Part of this virtual camera is called the image plane, which is like a movie screen. It’s attached to the virtual camera and moves with it at all times. The image on the virtual “movie screen” is called the plate, and shows the images taken on set — the actual film that was shot and scanned to be manipulated in the digital environment. In this way, when the matchmover looks through the virtual camera view, he or she sees what the camera operator saw on set (Figure 1-5).

The matchmover matches the focal length of the lens, and positions the camera in the same place in relation to the virtual set as it was in real life on the day of the shoot. Now, when looking through the virtual camera, the virtual set will line up

Figure 1-4 The virtual camera has a “movie screen,” or image plane, attached to it, and displays the film actually taken on set. The camera can be maneuvered around the virtual set just as the real-life camera is moved around the real-life set.
with the plate. The better the virtual set lines up with the plate, the better it’s said to “fit.”

At this point, the matchmover will turn to some automated software. If the camera on set did not move (called a “lockoff shot”), then the matchmover won’t have to worry about animating the camera. However, the matchmover will want to get a more accurate fit, or camera solution, than what he or she can get just by eye. This is where matchmoving specific software comes in.

**What the Computer Thinks About**

How does this mysterious software work? Well, on the surface, it’s actually pretty simple. You give the software some information, it chugs through some equations using the variables you’ve provided, and it spits out a solution. This solution is only as good as the information you give the software, of course!

**So What Are the Variables You Feed the Camera?**

You tell the software:

- That certain spots on the plate are important
- That they are important because they match certain points in the virtual set
Okay, but How Is That Done?

First, the important features on the plate are marked for the software by a process called 2D tracking. The 2D tracking software tells the computer where these features are on every frame of the sequence, in 2D (flat) space.

- That those points in the virtual set are located at these specific coordinates

**Figure 1-6** 2D tracking: important features are tracked with special 2D software.

**Figure 1-7** 2D track points on the plate (white) are associated with 3D locators (aqua) on the virtual set (dark blue).
Once all the important features have been tracked on the 2D plate, the matchmover identifies the corresponding 3D locations of those points on the virtual set, using 3D elements called locators. The software computes the correspondence over time, and this correlation between 2D tracking points and 3D locators is the basis of the 3D camera solution created by the matchmove software.

How do those numbers get crunched exactly? Well, I’m not actually a programmer, but I can tell you what the software is “thinking” about.

Imagine holding a string from the film plane of the virtual camera, and stretching it to one of the features on your plate. Remember, your camera and plate are locked to each other — they only move together. If you rotate your camera, the plate rotates out there in space. If you move back and forth, so does the image plane.

Now imagine that you have a few strings stretching from your camera to your plate — let’s say four (Figure 1-9). Imagine that you move your virtual camera around so that those strings also touch the 3D locators associated with those 2D features. Your
camera would line up with the virtual set and the plate perfectly, and there is only one place your virtual camera could be for all of the strings to touch all of the correct 3D locators at the same time, right? Now, say you did that on every frame of the shot. That’s exactly what the matchmove software does — for every 2D position on a plate and every associated 3D locator in the virtual set, the software “stretches a string” from the camera through the virtual location and to the plate, maneuvering the virtual camera until all the strings line up correctly. The technical term for this is triangulation, which means positioning the virtual camera by correlating the known measurements on the plate and virtual set. These known measurements were the ones surveyed and recorded by the on-set matchmove team during the original shoot.

Essentially, you’re telling the software, “Software, this bathroom tile here on the plate is right here on my model. This one right here is here on my model. This green box is right here on my model. I know how wide these tiles are, and how big the box is, so you can figure out the rest. Match it up — I’m going for coffee.”

Sometimes it works out smashingly, sometimes not (in other words, you’ll have to do some work!). But that’s the gist of it.

So, let’s look at what kinds of applications there are for this kind of computerthink.

What Kinds of Matchmove Tasks Are There?

Hopefully, that gives you a basic idea of what goes on in the office on a day-to-day basis. Matchmove isn’t just an automated-button-push-and-it’s-done-thing — it’s very hands-on and can be demanding! It’s also very challenging, and can be very entertaining as well. I promise.

There isn’t just one type of matchmove — the term actually comprises a few different functions. Let’s look at a few of these.

Camera Tracking

The most common type of matchmove is a camera track. In a camera track, you will create a duplicate of the live action camera in the virtual 3D world. This camera will have the same properties as the camera on the set, including film back, lens, height, tilt, and any movement the camera may have performed. You will typically (but not always) get information from the set, and you will use all this information, plus any other data you can gather, to help you place and animate the CG camera to match the live action camera.

Consider this example, in which the actor’s head and hands will be replaced with a flaming skeleton:
In this shot, the live action camera is mounted on a crane, moving over the motorcycle and up to the actor’s face (see “How do I know this is a crane shot?” on page 10). We want to match the motion of the camera in the live plate, animating the CG camera to match, so that when it’s later used to “photograph” the flame effects on the actor’s head, the flames will blend in seamlessly with the rest of the scene.

There are two ways to solve a camera track: surveyed and surveyless.

Surveyed Matchmoves

Many times, you will have a survey of the set your shot came from. This may be as elaborate as a full LIDAR survey, or it could be as simple as a few Polaroids with dimensions sketched on them to help you construct key props for your virtual set.

2D Tracking

The process of following the movement of a certain point, or feature, over time in a sequence of images.

3D Locators

In general, any point in the CG environment can be “located” by expressing its distance from a given coordinate point. In our environment, these measurements are given in units away from 0 along the X axis (side to side), the Y axis (up and down), and the Z axis (back and foreword from the computer screen). 3D locators are a type of 3D geometry used to mark locations in 3D space. On a CG set, they are placed on surfaces corresponding to the features tracked in 2D. For example, if the corner of a door were tracked in 2D on the plate, the corresponding door corner would have a 3D locator placed on it, designated and associated with that 2D feature.

Triangulation

The process of determining the location of a point in 3D space by calculating its relationship to known points.
Set data will also include the type of camera used (35 mm film camera or HD video camera, for example), as well as information about the lens used, and hopefully some information about the height and tilt of the lens at the beginning and end of the shot. These are normally estimates, but can be very useful as both a starting point and in determining whether your shot is working later on.

After gathering your data, you will then create 2D tracks corresponding to points on your virtual set. In the previous crane shot example, for instance, you might track features on the motorcycle and in the background (assuming that you have a model for those). Then you link the 2D data to the corresponding points on the virtual 3D set, and let the solver do its thing.

**Surveyless Matchmoves**

Occasionally, you may get a shot with no survey data, or no camera data, or no data at all; you will have to create a surveyless solution in this case. It’s virtually impossible, these days, to have absolutely no information at all, because of all the information at our fingertips online; see Chapter 3 to learn how to glean clues from your shot in order to create a virtual set.

Sometimes, though, even your best efforts at set building won’t work out; then you will try the surveyless method. In this method, automated software uses mathematical algorithms to pick hundreds of 2D points to track (versus the six or so you might need for a simple surveyed track), and then analyzes the motion of these points to create a camera move and a point cloud that approximates the 3D locations of those tracked points, in essence building a rudimentary set for you.

Instead of having known 2D and 3D locator values as in a surveyed matchmove, the automated matchmove software tracks hundreds of 2D points and analyzes the motion of these points in comparison to each other. When it recognizes that one large group of 2D track points moves together, the software presumes that group represents one 3D element in the virtual CG world. As the
software goes through each frame in the sequence, detecting these groups of points representing single objects, it also compares the motion of those objects to each other, looking for parallax, rotation, and translation cues through mathematical equations. Then, after that analysis, it generates a point cloud, the actual 3D locators generated by the analysis of the comparative motion of the 2D tracks. Think of it as hundreds of tiny locators that have been projected onto the plate, and then pushed out to reveal the 3D shape of the actual objects that were photographed, not unlike those boxes with the silver pins you push forward to reveal the 3D shape of your hand.

A fully automated solution like this is usually, but not always my last resort, though I know many artists who use automated solutions as the first step in their personal process with great success. I often find that surveyless solutions aren't worth the trouble, especially if you can create a rudimentary set to work with yourself. I’ve even been told by sups to spend no more than two hours on a surveyless solution, because if an automated solver can’t get the shot done in that time, it probably won’t ever get it.
Object Matchmove

In addition to matching the camera in a particular shot, there may also be practical elements in your shot that also need to be recreated. This type of matchmoving, called object matchmove, can be done through an automated solver or by hand animating in your 3D software. For example, some CG element in the final shot might affect practical elements in the plate. In Figure 1-13, for example, the practical robot costume will have added arms, legs, and other elements, and the arms and legs interact with the set—he's tearing up the house! The destruction wrought by this robot will cause smoke, dust clouds, and sparks which will light and shadow the surrounding walls, floor, and other props. In turn, the room will be reflected in the robot’s body. In this case, you will need to match all the props in the room, as well as the robot costumed stunt man in the scene after the camera move has been through the review process and approved as a final. If the furniture were moving, or bricks were falling out of the fireplace (which they did), you would to animate each to match the plate. In this way, artists

Figure 1-13 In this shot, CG arms, legs, and torso will be added to the robot costume, so matching the practical very closely is important. “Zathura: A Space Adventure” © 2005 Columbia Pictures Industries, Inc. All Rights Reserved. Courtesy of Columbia Pictures.

Figure 1-14 In addition to the practical costume, all the other props in the room must be matched so that the CG robot can interact with them. “Zathura: A Space Adventure” © 2005 Columbia Pictures Industries, Inc. All Rights Reserved. Courtesy of Columbia Pictures.
further along the pipeline will know how the smoke, dust, and robot interact with the practical elements when seen in the virtual world. See Chapter 12, “Real Life Shot: Character and Object Rotomation,” for more details.

**Character Matchmove**

Character matchmove — which I refer to as *rotomation* — is, as you might guess, in the same family as object matchmove. Take Figures 1-15 and 1-16, for example. Once the camera matchmove has been approved, the matchmove artist would then import a CG character prepared by the modeling and rigging departments, and animate it to match Geena Davis’ movements. Then this animated character is passed to other departments down the line, so that Margalo has a place to sit. The character animators will be able to time Margalo’s movements with Geena’s hand motion just as if she were a real bird on a real finger. In addition, both Stuart and Margalo need to know where to look when talking to mom, so Geena’s face must be matched as well.

Some matchmovers are daunted by character animation, but you shouldn’t be; I will outline many tricks and procedures later so that character matching will be your favorite task! See Chapter 10 for more details.

**Other Uses**

Sometimes, especially at the beginning of a show, you might need to perform other matchmove tasks in advance of primary photography. That sounds backward, right? Not necessarily.

Sometimes matchmoves are used to output motion control data in order to line up an existing plate element with elements that have yet to be shot. For example, one might get a shot of a miniature set with pyrotechnic effects, match the camera used for that element, and output that camera information so that the actors can be filmed separately with a motion control camera that mimics the camera used in the miniature set. This way the actors can be integrated into the miniature background seamlessly, with the same perspective and camera move.

Preliminary matchmoves can also be used to pass information on to other departments. For example, a sweeping, 360-degree camera move on a set which needs to be digitally extended might be roughly matched so that the modeling