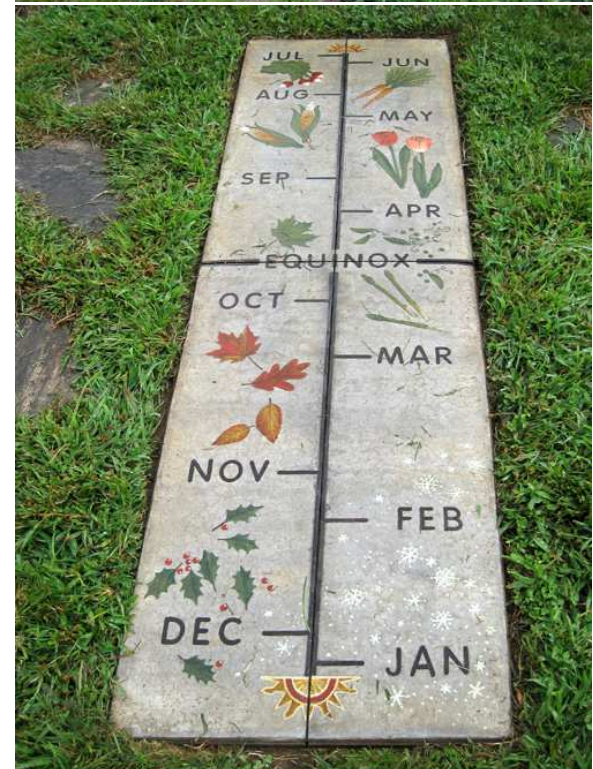


Making An Analemmatic Sundial

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North American Sundial Society
June 2013**

Analemmatic Sundials – The Human Sundial

- **The Analemmatic Sundial or “Human” Sundial was first described by M. de Vaulezard in 1640 in a “Treatise on the Usage of the Analemmatic Dial”**
- **The dial consists of a central way for the shadow casting gnomon.**
 - The gnomon is positioned according to the date
 - The gnomon height is of no consequence, hence ideal for “human” gnomons of varying size
- **The hour markers are positioned on an ellipse surrounding the central way**
 - The size of the ellipse is designed to fit human proportions ... typically with a maximum radius of 8-10 feet
 - The shape of the ellipse is set by latitude



Step 1 Decide on the Sundial Location

- Find a level, sunny area
- **Could be a level grassy area away from trees.**
 - Use pavers to create a walk way where the person will stand to cast his/her shadow
 - Use pavers or other markers for the hour marks
 - Use acrylic paint to create the monthly standing marks on the walkway and hour marks
- **Could be unused, level area of the playground away from basketball hoops or other equipment**
 - Use acrylic paint to create the monthly standing marks on the walkway and hour marks



Step 2 Tools and Materials Required

- **Hammer and about 20 nails**
 - **Grass:** use long nails with ribbons so they don't get lost
 - **Asphalt:** use concrete or brick nails. Paint the tops yellow or orange so they don't get lost
- **Chalk Line**
- **Two Tape Measures**
 - Must extend at least 12 feet
- **Paint and Masking Tape**
 - **Asphalt:** Use regular acrylic latex paint. Some acrylic paint comes by various names such as "Parking Lot Striping Paint", "Traffic Paint" or "Athletic Field Paint". Behr, Glidden and Rustoleum all sell versions of this "traffic paint" at Home Depot and Lowe's.
 - **Concrete playgrounds and pavers stones:** will require a sealant before applying the acrylic latex paint. This is available at Home Depot and Lowe's as well.
 - **BEWARE:** The masking tape will not work well and may allow "run under" of the paint. Nevertheless, it provides a good guiding line and prevents small mistakes.

Step 2 Tools and Materials Required (cont'd)

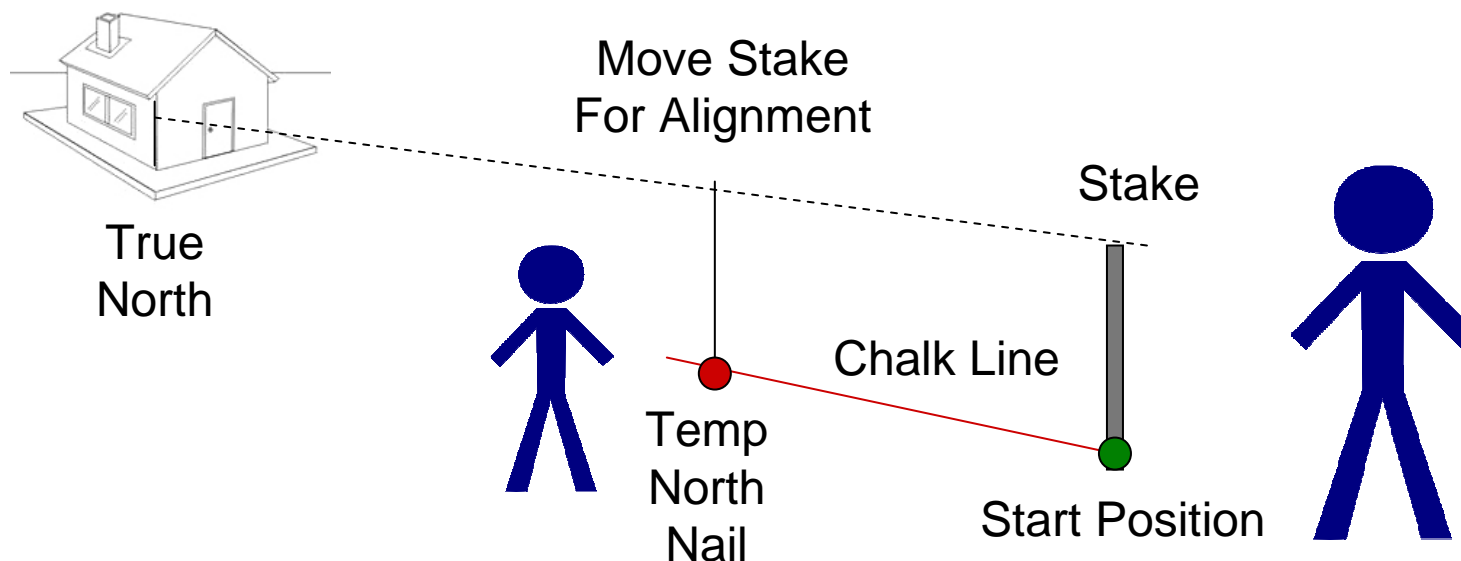
- **Finding North Using Google Earth**
 - Use Google Earth on Computer to find your position on the earth
 - Two stakes (about 2 foot long)
 - Chalk Line
 - Hammer and Nails
- **Finding North Using Noon Shadow**
 - Equation of Time from NOAA:
<http://www.esrl.noaa.gov/gmd/grad/solcalc/azel.html>
 - Watch set to time from USNO atomic clock:
<http://tycho.usno.navy.mil/simpletime.html>
 - Tripod, Plumb Bob and string to hold the Plumb Bob on Tripod
- **Finding North Using Stick Shadow**
 - One stake (about 2 foot long)
 - Carpenter's level for finding vertical
 - Hammer and Nails

Step 3 Mark the Start Position

- **Start at the position that will be the center of the sundial. The dial will occupy an area about 8 foot to either side (east-west) and about 5 foot to the north and about 4 foot to the south.**
- **Prepare your marking nails**
 - **Grassy Areas:** use a large nails with a ribbon or plastic flag so that you can easily find the nail again. You'll need about 20 flagged nails in all.
 - **Asphalt Playgrounds:** use small concrete nails. Paint the head of the nails yellow or orange. You can also use a ribbon.
- **Hammer one nail into the asphalt or grass and mark the start position of your sundial.**

Step 4A Find North at the Start Position - Google

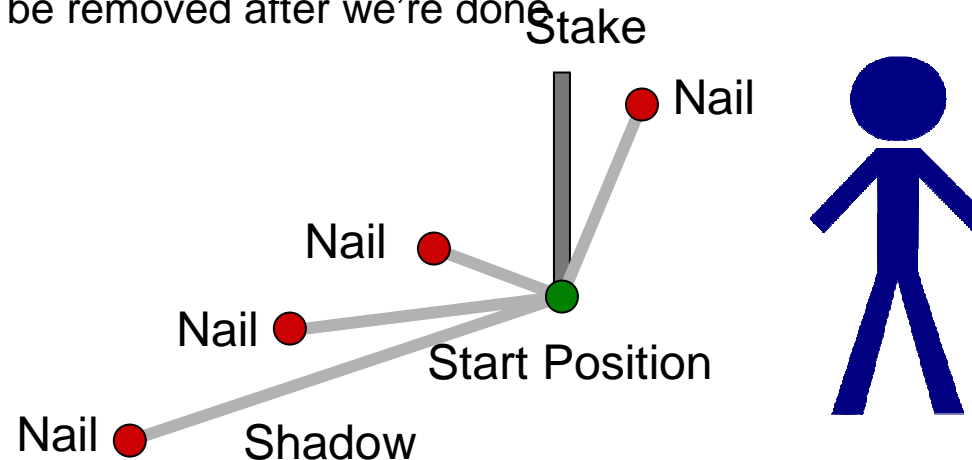
- This takes two people
- Use Google Earth to locate your position and a distant (~300 feet) identifiable object that is directly north, such as a portion of a building roof, a tree, a distant sign, etc.
 - Place a stake at the start position nail
 - About 5 feet away have someone move a second stake until it aligns to the background object. Hammer it in the ground



Step 4B Find North at the Start Position - Shadows

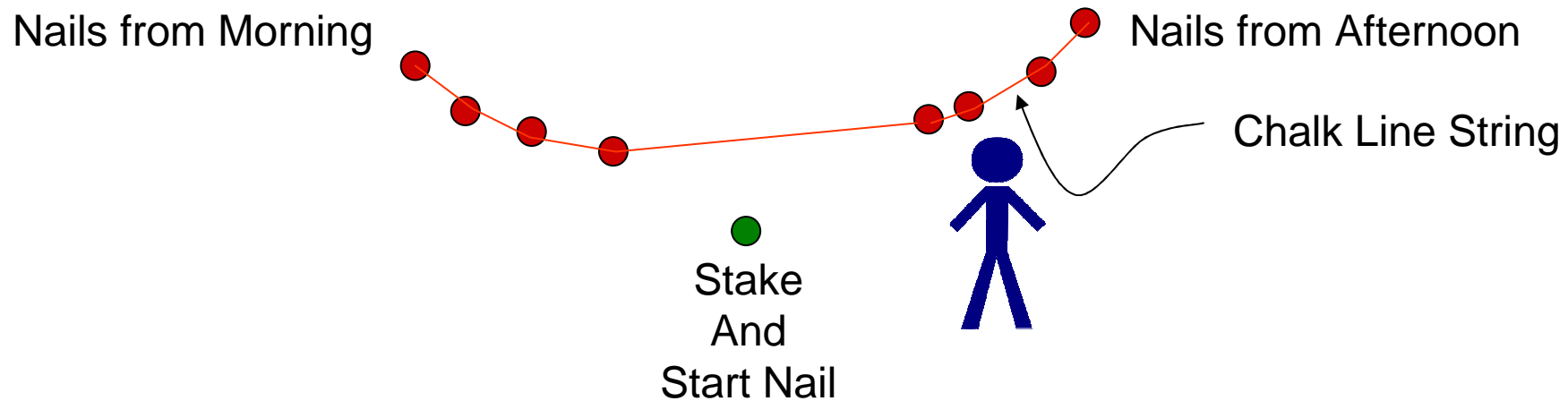
- **This takes one person for most of the day. At late afternoon, need second person**
- **Place a stake at the start position nail**
- **Measure stake's shadow in morning and afternoon**
 - In the morning, from 9am to 11am, every half hour place a nail at the position of the stake's shadow tip.
 - In the afternoon, from 1pm to 4pm, every half hour place a nail at the position of the stake's shadow tip.
 - **IMPORTANT:** must nail at the tip of the shadow!
 - **IMPORTANT:** don't hammer the nails all the way down. They are temporary and will be removed after we're done.

- **Next Slide Please**



Step 4B Find North at the Start Position - Shadows

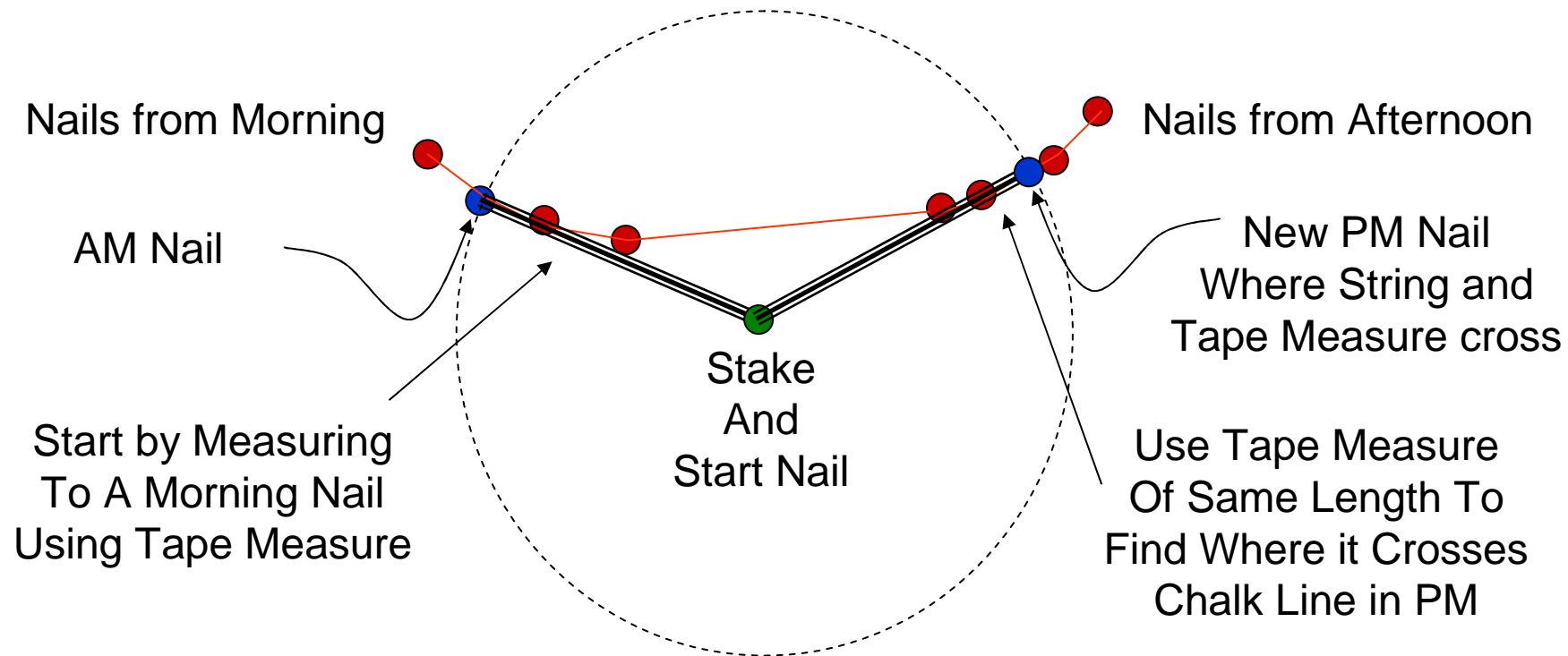
- With all the nails in place, use the chalk line string to “connect” the string from nail to nail. Here’s the top down view



- Now use the tape measure from the stake at the start nail. Measure out to the 9:30am nail (or other early morning nail ... it really doesn't matter. Remember the shadow nail (place a marker by it's side).
- Using the same tape measure length, go to the afternoon side and find where that tape measure length crosses the string. Place a new nail at that point.

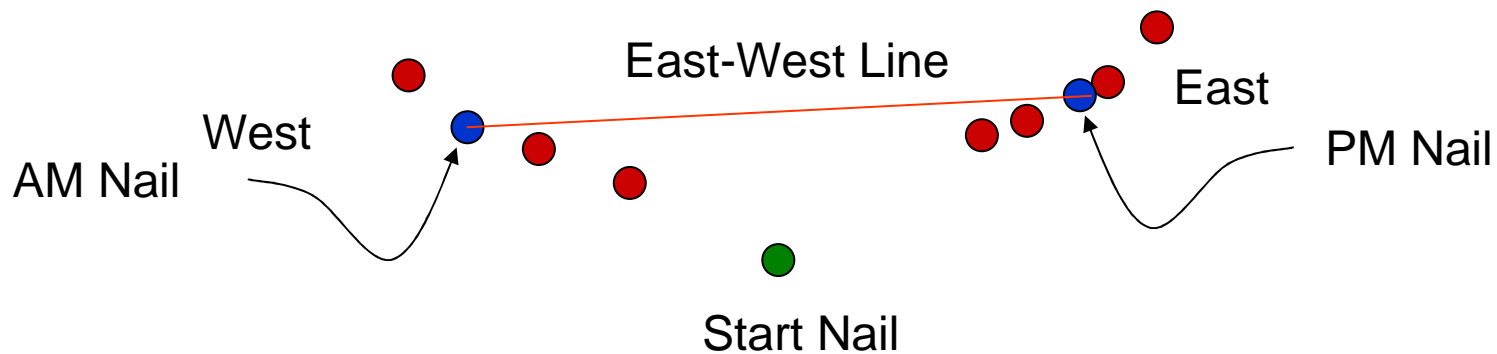
Step 4B Find North at the Start Position - Shadows

- Use Tape Measure to Find Places of String Crossing

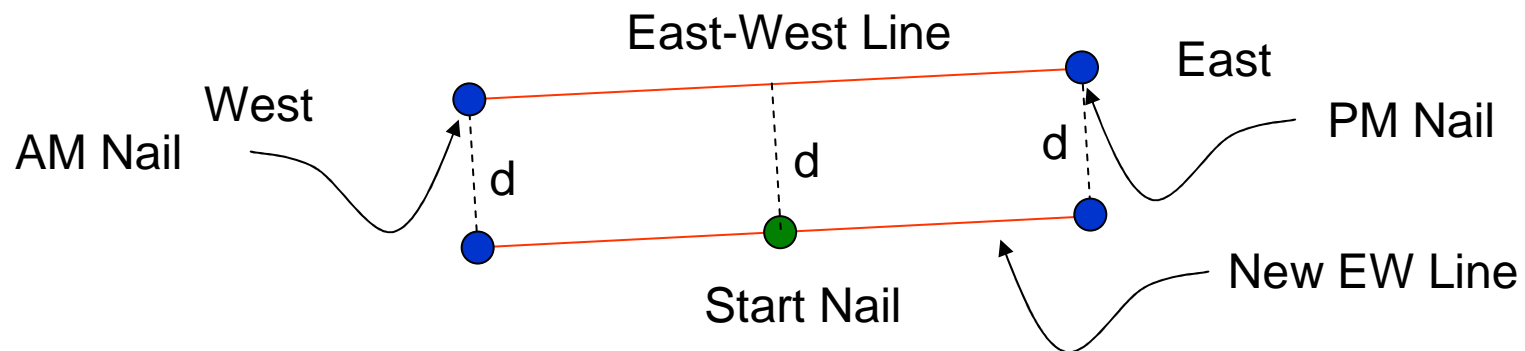


Step 4B Find North at the Start Position - Shadows

- Next, take the chalk line string and connect the AM and PM Nails. This chalk line string between the AM and PM Nails is now aligned East-West



- Measure the closest distance between the Start Nail and the E-W string. Repeat that distance from the AM and PM Nail.
- Put in new AM and PM Nails. Move the chalk line string between these nails. The new E-W line goes through the Start Nail



Step4C Find North at the Start Position - Plumb

- Use NOAA Solar Calculator
- <http://www.esrl.noaa.gov/gmd/grad/solcalc/azel.html>
- Example:

Lat: 44° 20' 22"

Lon: 72° 45' 14"

Select "Enter Lat/Long"
 Select Date (e.g. June 15 2013)
 Select Offset to UTC = 5hr for
 Eastern Time Zone
 Select 12:00:00 (24hr)

 Click Calculate Position

EOT = -0.58 min

DEPARTMENT OF COMMERCE
 UNITED STATES OF AMERICA

NOAA ESRL
Solar Position Calculator
 Earth System Research Lab

City:	Deg:	Min:	Sec:	Time Zone	
Enter Lat/Long ->	Lat: North=+ South=-	44	20	22	Offset to UTC (MST=+7):
Click here for help finding your lat/long coordinates	Long: East=- West=+	72	45	14	5
Note: To manually enter latitude/longitude, select Enter Lat/Long -> from the City pulldown box, and enter the values in the text boxes to the right.					
Month:	Day:	Year (e.g. 2000):	Time: (hh:mm:ss)		
June	15	2013	12	: 00	: 00
<input type="radio"/> AM <input type="radio"/> PM <input checked="" type="radio"/> 24hr					
Calculate Solar Position					
Equation of Time (minutes):	Solar Declination (degrees):	Solar Azimuth:	Solar Elevation:	cosine of solar zenith angle	
-0.58	23.33	185.37	68.92	0.9331	
Azimuth is measured in degrees clockwise from north. Elevation is measured in degrees up from the horizon. Az & El both report <i>dark</i> after astronomical twilight .					

Step 4C Find North at the Start Position - Plumb

- Set a tripod with a hanging plumb bob directly over the Start Nail
- When the sun is on the local meridian, the shadow points due North. We need math to find Local Solar Time

Start with you longitude	72.75389 W	Dial Longitude (W)
Subtract time zone meridian	75.00000 W	Eastern Time Zone

Difference (could be +/-)	-2.43611 deg	(Minus is East of Meridian)
Multiply by 4 deg into minutes	-9.74444 min	
Subtract NOAA Equation of Time	- -0.58 min	June 15, 2013 12pm EDT

Time Correction	-9.16 min	Standard Time
Add Daylight Saving Time	60.00 min	

Adjust	-50.84 min	
Clock Time + Adjust = Local Solar Time		
Clock Time = Local Solar Time – Adjust		
Clock Time = 12 hr (noon) + 50.84 min		
Clock Time = 12: 50: 50		

Step 4C Find North at the Start Position - Plumb

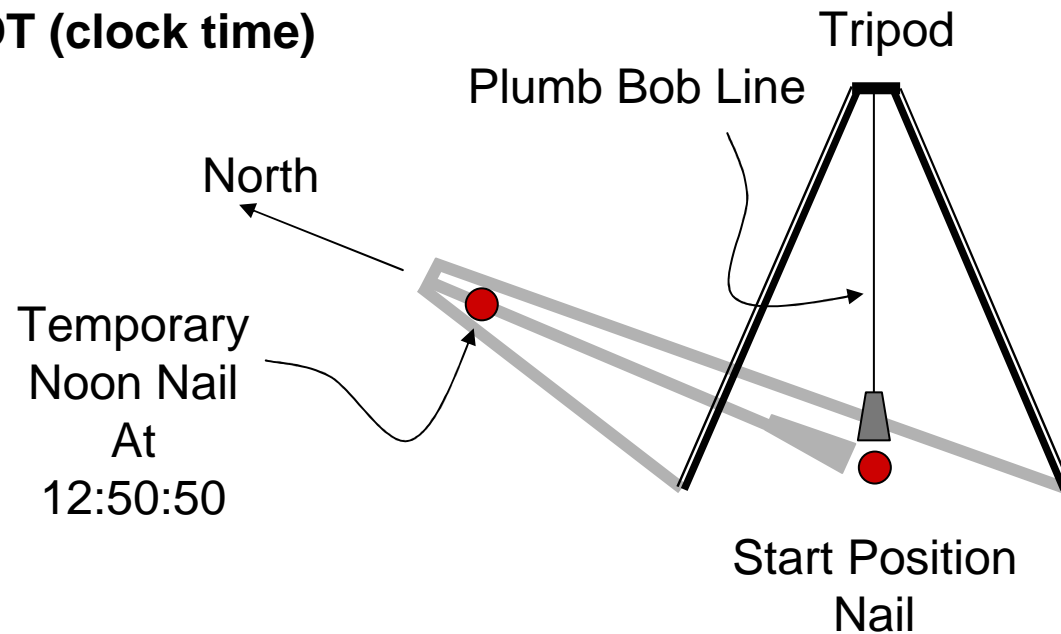
- In our example, we've determined that the shadow of the plumb bob string will point due North:

Date: June 15, 2013

Time: 12: 50: 50 EDT (clock time)

For Lat: $44^{\circ} 20' 22''$

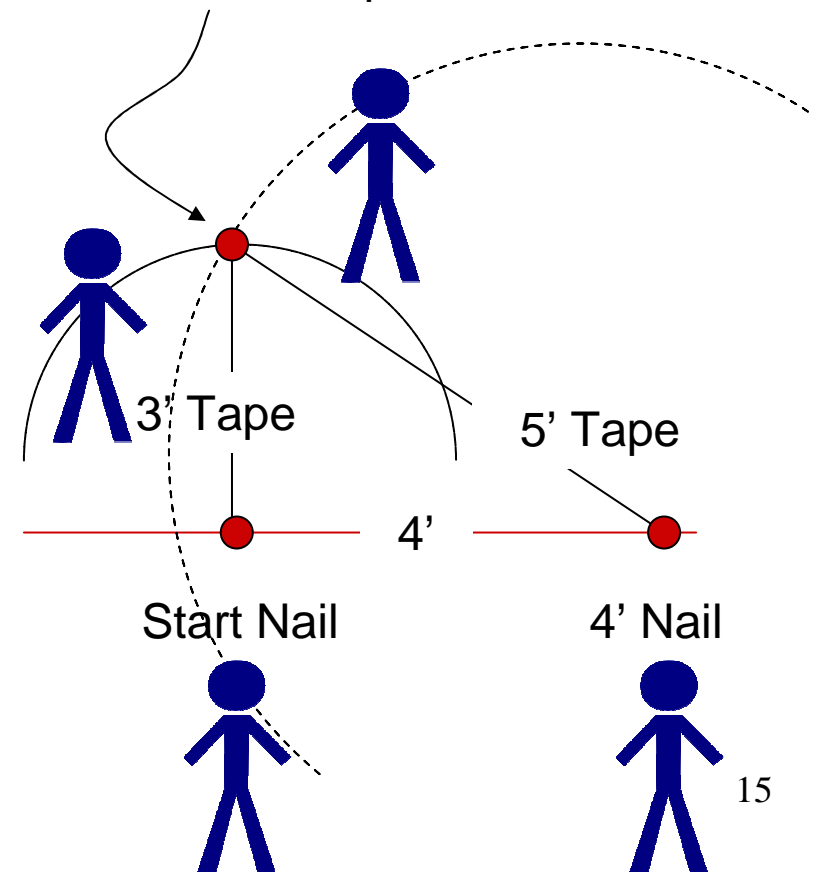
Lon: $72^{\circ} 45' 14''$



Step 5A Create N-S and E-W Lines

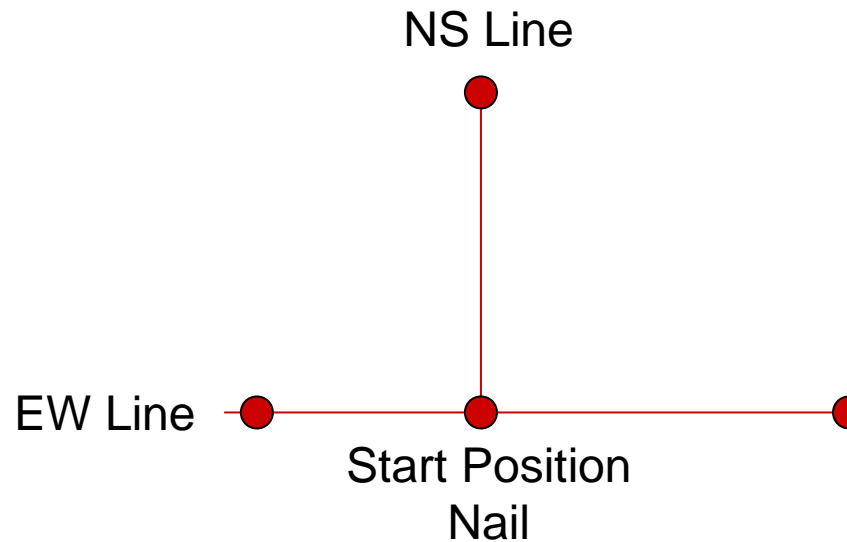
- **Regardless of the method, you've now established either an E-W Line or N-S Line**
- **We use the 3-4-5 right triangle to construct a right angle and complete the additional necessary line.**
- **Here we show an existing EW line and need to construct a NS line.**
- **Make sure that existing lines are extended at least 4 foot past the start position Nail**
- **With 4 people**
 - One holds the tape measure starting at the Start Nail
 - One holds the tape measure starting at the 4-foot Nail
 - One moves the tape at the 3-foot mark
 - One moves the other tape at the 5-foot mark

Where the two tapes
Cross (3' and 5')
Put a Nail at that point



Step 5B Create N-S and E-W Lines


- Now we should have EW and NS nails that go through the starting nail position




- Our next step is to establish critical points on the NS and EW lines measured from the Start Nail

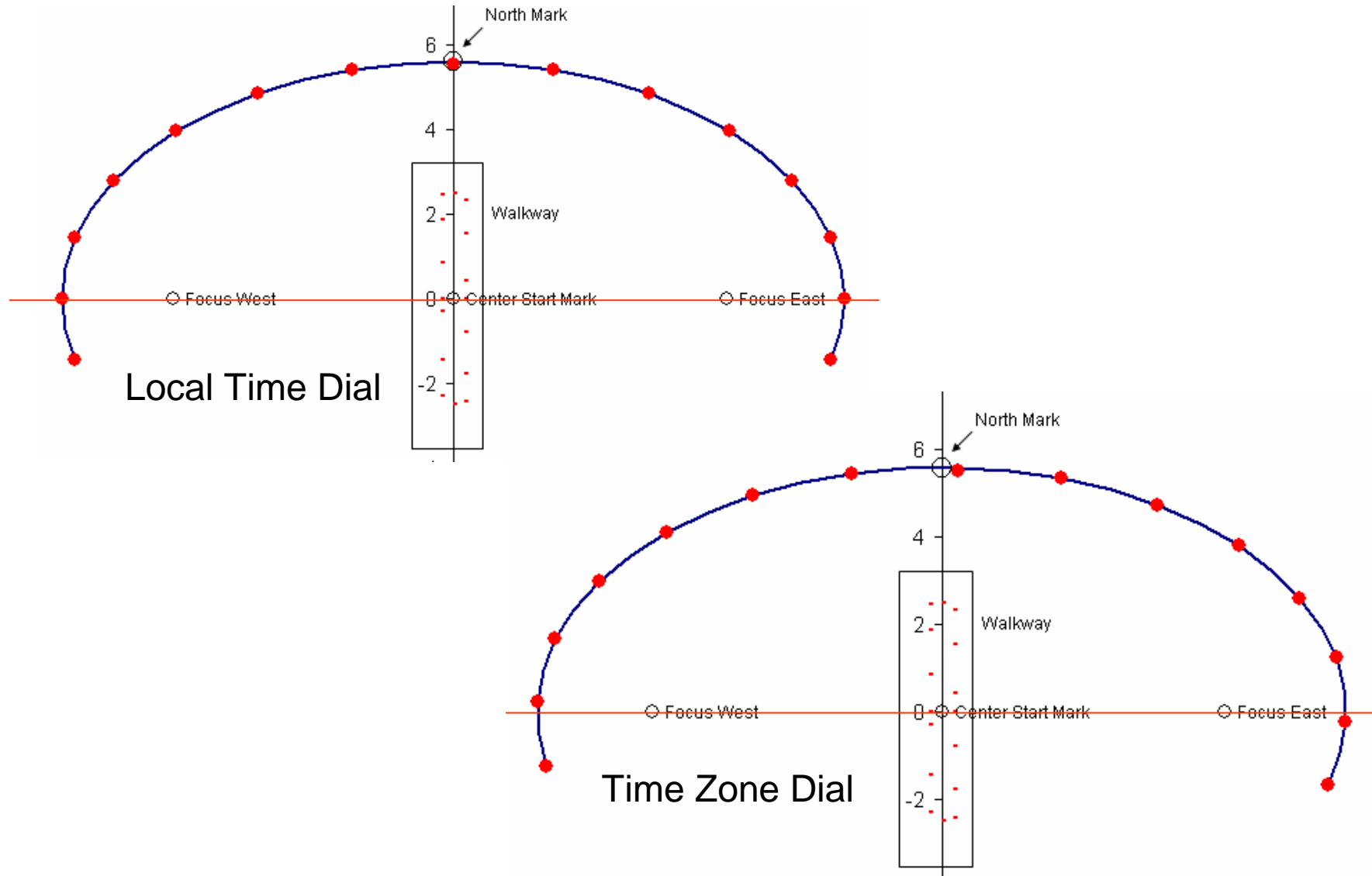
Step 6A Enter Lat/Lon and Dial Parameters

- **Use the Analemmatic Spreadsheet**
 - Enter Latitude (decimal degrees)
 - Enter Longitude (decimal degrees)
 - Enter Dial Size (suggest 8 feet)
 - **Note: Just enter the numbers, the spreadsheet creates “N”, “W”, and “feet”**
- **Set the Dial Construction for Time Zone or Local Solar Time**
 - If you want to use “Zone Time” enter your time zone. Eastern Time Zone is at exactly 75.0000 degrees. This will move the Noon Mark. In the given example, the Noon Mark will be moved 9 minutes 45 sec to the east.
 - If you want to use “Local Solar Time” enter your longitude as the Time Zone. This will make the Noon Mark exactly due North

ENTER LOCATION PARAMETERS			
Latitude	44.3395 N	<=ENTER	
Scale	8.0 feet	<=ENTER	
Longitude	72.7539 W	<=ENTER	
TimeZone	75.0000 W	<=ENTER	

ENTER LOCATION PARAMETERS			
Latitude	44.3395 N	<=ENTER	
Scale	8.0 feet	<=ENTER	
Longitude	72.7539 W	<=ENTER	
TimeZone	72.7539 W	<=ENTER	

Step 6B Local Time Dial vs Time Zone Dial



Step 7A Mark East and West Focal Points

- **Use the Analemmatic Spreadsheet**

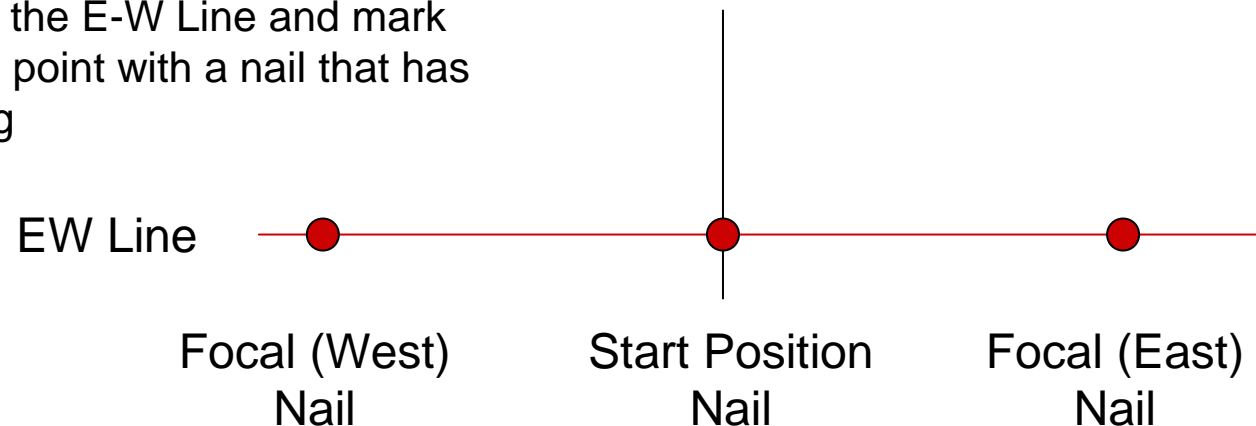
- Read the focal East and focal West distances



Ellipse Axes and Focal Points			
Ellipse		feet	inches
x	a	8	--
y	b	5	7
x	focus East	5	8 1/2
x	focus West	-5	8 1/2
y	North Mark	5	7

- **Mark focal points on E-W line**

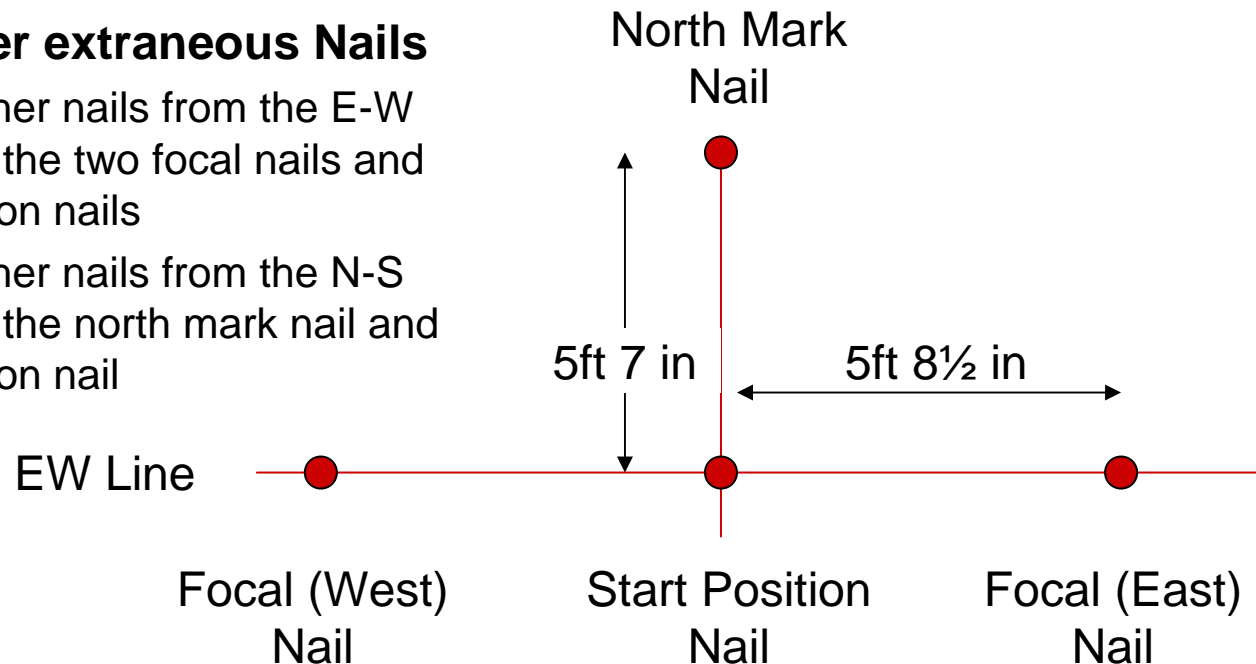
- From the start location nail, measure East (+) along the E-W Line and mark the East focal point with a nail that has a ribbon or flag
- Our example is 5 foot 8½ inches
- From the start location nail, measure West (-) along the E-W Line and mark the West focal point with a nail that has a ribbon or flag



Step 7B Make North Mark

- **Use the Analemmatic Spreadsheet**
 - Read the North Mark distance
- **Create North Mark on N-S Line**
 - From the start location nail, measure North and make the North Mark with a nail that has a ribbon or flag
 - Our example is 5 foot 7 inches
- **Remove all other extraneous Nails**
 - Remove all other nails from the E-W Line EXCEPT the two focal nails and the start position nails
 - Remove all other nails from the N-S Line EXCEPT the north mark nail and the start location nail

Ellipse Axes and Focal Points			
Ellipse		feet	inches
x	a	8	--
y	b	5	7
x	focus East	5	8 1/2
x	focus West	-5	8 1/2
y	North Mark	5	7



Step 8A Mark Morning Hours

- **Use the Analemmatic Spreadsheet**

- Use the Morning Hour Table

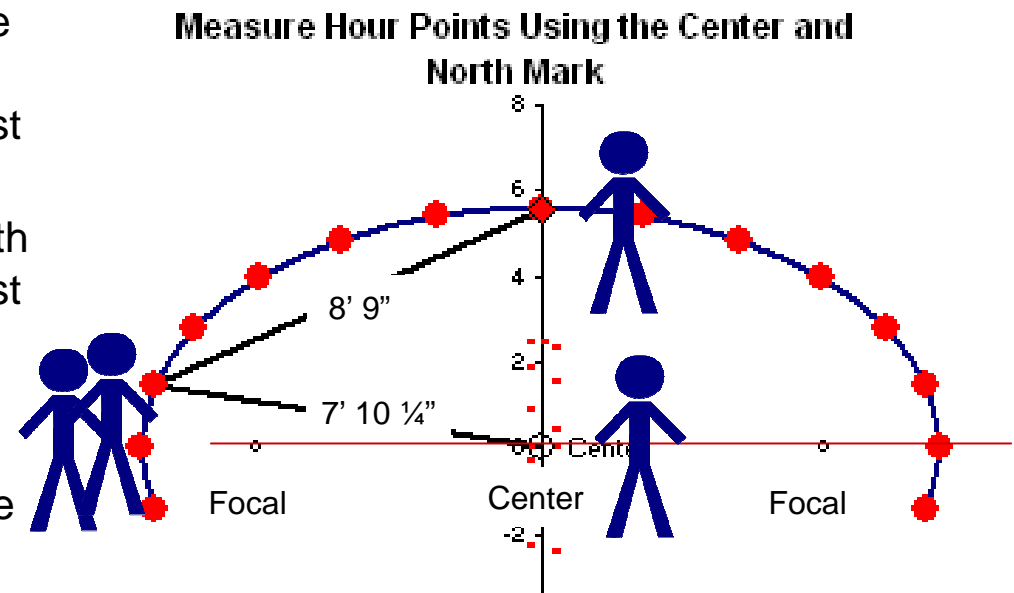
Standard Time		West	North	Distance from center (0,0)		Distance from north mark	
Hour	Minute	x (feet)	y (feet)	feet	inches	feet	inches
5	0	-7.73	-1.45	7	10 1/4	10	5 1/4
5	30	-7.93	-0.73	7	11 1/2	10	1 1/2
6	0	-8.00	0.00	8	--	9	9
6	30	-7.93	0.73	7	11 1/2	9	3 1/2
7	0	-7.73	1.45	7	10 1/4	8	9
7	30	-7.39	2.14	7	8 1/4	8	1 3/4
8	0	-6.93	2.80	7	5 1/2	7	5 1/2
8	30	-6.35	3.40	7	2 1/4	6	8 1/2
9	0	-5.66	3.95	6	10 3/4	5	10 1/2

- Once you get going, you can do the 5, 6, 7, 8, and 9am hour marks very rapidly.
- Suggest that you use only the hour distances. Ignore the half-hour values (at least until you get the dial laid out and decide to add the additional markers)
- The next step requires 5 people ... so prepare !!

Step 8B Mark Morning Hours

- **Measure from the Start Point and from the North Mark**

- One person holds the tape measure on the start point (center) A second person runs the tape out to the West
- One person holds their tape measure on the north mark. A fourth person runs the tape out to the West
- Use the table distances and cross the tapes until they match at those distances. It helps to have a fifth person with clip board reminding the tape “runners” of the distance they need to use.



- **Example: 7am Marker**



















- From Center 7ft 10¼ in
- From North Mark 8 ft 9 in

Step 8C Mark Afternoon Hours

- Now that you've done the 5am – 9am, flip to the afternoon hours and do 3pm – 7pm
 - Use the Afternoon Hour Table

Standard Time		West	North
Hour	Minute	x (feet)	y (feet)

Distance from center (0,0)		Distance from north mark	
feet	inches	feet	inches

	3	0	5.66	3.95	6	10 3/4	5	10 1/2	
	3	30	6.35	3.40	7	2 1/4	6	8 1/2	
	4	0	6.93	2.80	7	5 1/2	7	5 1/2	
	4	30	7.39	2.14	7	8 1/4	8	1 3/4	
	5	0	7.73	1.45	7	10 1/4	8	9	
	5	30	7.93	0.73	7	11 1/2	9	3 1/2	
	6	0	8.00	0.00	8	--	9	9	
	6	30	7.93	-0.73	7	11 1/2	10	1 1/2	
	7	0	7.73	-1.45	7	10 1/4	10	5 1/4	

Step 8A Mark Mid-Day Hours

- For Mid-Day Hour Marks, we use the same technique, but the measuring references are the two focal points.
 - Use the Mid-Day Table

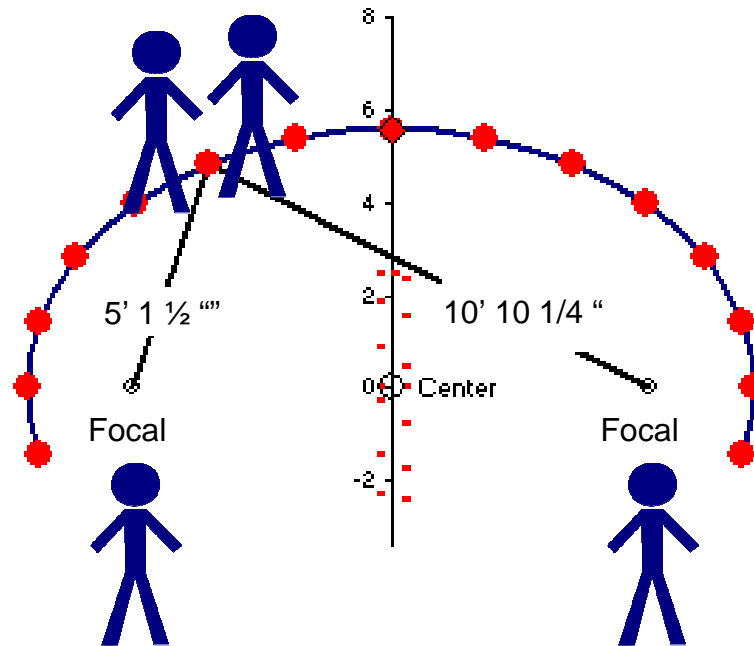
Standard Time		West	North	Distance from west focus (-)		Distance from east focus (+)	
Hour	Minute	x (feet)	y (feet)	feet	inches	feet	inches
9	0	-5.66	3.95	3	11 1/4	12	1/2
9	30	-4.87	4.44	4	6	11	5 3/4
10	0	-4.00	4.84	5	1 1/2	10	10 1/4
10	30	-3.06	5.17	5	9 1/2	10	2 1/4
11	0	-2.07	5.40	6	6	9	5 3/4
11	30	-1.04	5.54	7	3	8	8 3/4
12	0	0.00	5.59	8	--	8	--
12	30	1.04	5.54	8	8 3/4	7	3
1	0	2.07	5.40	9	5 3/4	6	6
1	30	3.06	5.17	10	2 1/4	5	9 1/2
2	0	4.00	4.84	10	10 1/4	5	1 1/2
2	30	4.87	4.44	11	5 3/4	4	6
3	0	5.66	3.95	12	1/2	3	11 1/4

- Again this requires 5 people

Step 8B Mark Mid-Day Hours

- For Mid-Day Hour Marks, use the same measuring technique, but the measuring references are from the two focal points.
 - Example is for 10AM
 - Note: Make Sure you Don't confuse the East and West Focal Point Distances

Measure Hour Points Using the Two Foci

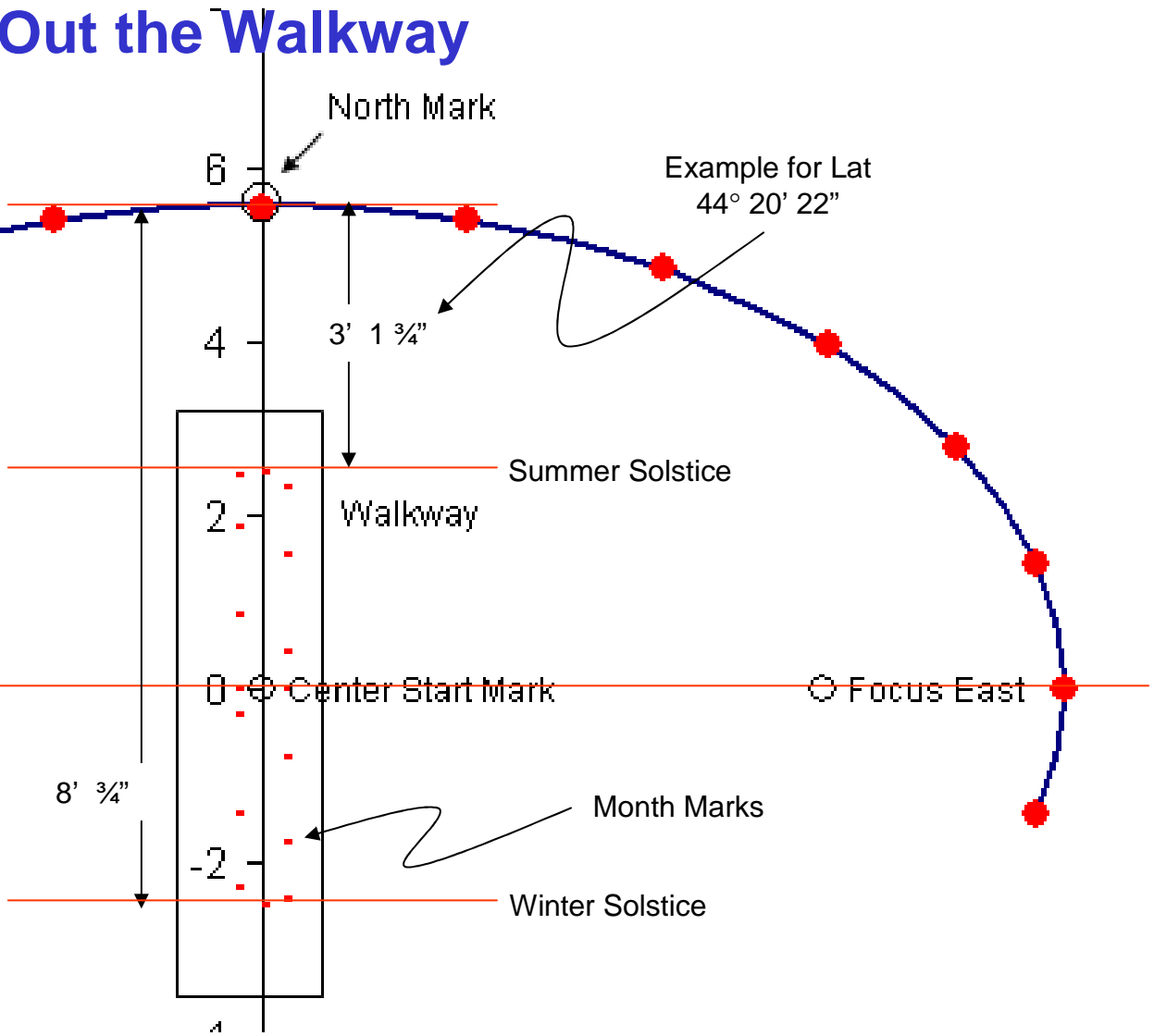


Step 9A Lay Out the Walkway

- **All Measurements are made from the North Mark.**
 - If you've selected Local Solar Time, then the North Mark and the 12 noon Marker are the same
 - If you've selected the Time Zone option, BE CAREFUL. The North Mark and the 12 noon Marker will be close to each other, but they are not the same. Only the North Mark lays on the N-S line running through the dial center start point
- **Marks are made for the first of each month, plus special marks for the solstices and equinoxes**

Walkway Place to Stand						
Sun			Measure South From N-Mark			
Month	Day	(deg)	feet	inches	E/W mark	
Solstice	356	-23.44	8	3/4	0	
Jan 1	1	-23.03	8	1/4	0.25	
Feb 1	32	-17.22	7	4 1/4	0.25	
Mar 1	60	-7.74	6	4 1/4	0.25	
Equinox	80	0.00	5	7	0.25	
Apr 1	91	4.38	5	1 3/4	0.25	
May 1	121	14.96	4	1/2	0.25	
Jun 1	152	22.00	3	3 1/4	0.25	
Solstice	173	23.44	3	1 1/4	0	
Jul 1	182	23.13	3	1 3/4	-0.25	
Aug 1	213	18.12	3	8 1/2	-0.25	
Sep 1	244	8.43	4	8 3/4	-0.25	
Equinox	266	0.00	5	7	-0.25	
Oct 1	274	-3.02	5	10 1/2	-0.25	
Nov 1	305	-14.30	7	1/2	-0.25	
Dec 1	335	-21.74	7	10 1/4	-0.25	
Solstice	356	-23.44	8	3/4	0	

Step 9B Lay Out the Walkway



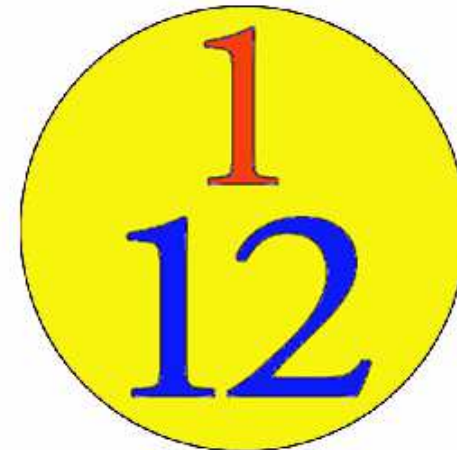
Step 9C Lay Out the Walkway

- **Typical Layout**
 - Notice the Central Line. You put one foot on each side and stand on the date.
 - Notice that June and December are very squashed, so you may have to use thin month separator lines.
 - If this is a paver walkway, extend it north beyond the summer solstice mark and south beyond the winter solstice mark so that you have a place to stand.



Step 10 Hour Marks

- **You can make the hour marks of any design.**
 - Circular with standard time hours (that is, 12pm near or at the North Mark)
 - If the dial is only used during summer weather, daylight savings time can be used. In that case the 1pm is near or at the North Mark
 - Maybe you want to show both standard and daylight savings time. Use two different colors.
 - Make the hour markers 6-8 inches in diameter



Some Analemmatic Dials



Big Plastic Template Done Inside First



More Analemmatic Dials



More Analemmatic Dials

