

COURSE

Map Reading and Navigation

10 Chapters

Philip Osztromok

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MAP READING AND NAVIGATION

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Map Reading and Navigation

Course 1 · Chapter 1 · Reading a Map: Scale, Symbols and North

A map is a small, flat picture of a large piece of ground, drawn so that you can measure it and find your way across it. Before you can navigate you must be able to read one: how much ground it covers, what its symbols mean, and which way is north. This chapter covers those three things. Later chapters add grid references, contours, the compass, bearings, route planning and what to do when the weather turns.

What a Map Shows

A map is a selection, not a copy. The mapmaker leaves out most of what is on the ground and keeps what a walker needs: paths, roads, rivers, buildings, woods, and the shape of the land. Because the choice is made for you, you must know what a map includes and what it leaves out, such as a path that has become overgrown or a fence added last year.

Scale

The link between a distance on the paper and the same distance on the ground.

Symbols

Small pictures and coloured lines that stand for real features. The legend (or key) explains them.

Direction

Most maps are drawn with north at the top, and mark north with an arrow or the grid lines.

Date

Every map is out of date the day it is printed. Check the edition or revision date in the margin.

Scale

Scale is written as a ratio. On a 1:50,000 map, 1 unit on the paper is 50,000 of the same unit on the ground. So 1 cm on the map is 50,000 cm, which is 500 m, on the ground. A larger scale number means a smaller, less detailed map of a wider area.

Scale	1 cm on the map	Typical use
1:25,000	250 m	Walking and detailed route finding (many walkers' favourite)
1:50,000	500 m	Walking and general travel
1:250,000	2.5 km	Planning a long journey by road

The conversion is always the same: multiply the map distance by the scale number, then change the units. The quick way is to learn the two common cases by heart: at 1:25,000 every 4 cm is 1 km, and at 1:50,000 every 2 cm is 1 km.

```
# ground distance = map distance x scale number
scale    = 50000          # a 1:50,000 map
map_cm   = 7.5
ground_cm = map_cm * scale     # 375,000 cm
ground_m  = ground_cm / 100  # 3,750 m
ground_km = ground_m / 1000   # 3.75 km
```

> **Use the scale bar**
>
> Most maps print a scale bar in the margin. Lay the edge of a piece of paper along your route, mark the distance, then hold it against the bar. This also copes with the paper shrinking or being printed at the wrong size, which a ratio alone cannot.

Symbols and the Legend

You do not need to memorise every symbol, but you should know the main groups and always check the legend for the rest. Colour does a lot of the work. The pattern below is common on walking maps, but the exact colours and symbols vary between publishers and countries (check the legend of your own map).

Colour	Usually means
Blue	Water: rivers, lakes, the sea, and often streams and ponds

Colour	Usually means
Green	Woodland, forest or other vegetation
Brown	Contour lines (the shape of the land; see Map Reading and Navigation 3)
Black	Buildings, boundaries, names and many paths
Red or orange	Main roads, and sometimes rights of way or access land

> **A path on the map is not a promise**
>
> A dotted line shows that a path existed when the map was surveyed. It may be faint, flooded or gone. Rights of way and access rules also differ between countries, so a path being drawn does not always mean you may use it.

Finding North

A map has a fixed direction. On most maps the top edge is north and the grid lines run north-south and east-west. That is **grid north**. The north that a compass needle points to is **magnetic north**, and it is slightly different, and the difference changes over the years and from place to place. Chapter 4 explains this in detail; for now just remember that the map, the compass and the real north pole are three slightly different things (check the declination diagram in your map's margin).

```
# orient a map without a compass
1. find a linear feature you can see (a road, a river, a wall)
2. turn the map until that line on paper points the same way
3. check the features beside you match the map around you
4. your position is now somewhere on the map beside them
```

Reading a Map in Order

Experienced walkers read a map the same way every time, and the habit stops mistakes. Work from the big picture to the detail.

Step	Ask
1. Edition	How old is this map? What has probably changed?
2. Scale	How much ground does one centimetre cover?
3. Legend	What do the symbols and colours mean on this map?
4. North	Which way is north, and is the map oriented?
5. Features	Which large, obvious features (rivers, roads, woods) can I match to the ground?

Challenges

EXERCISE 1

Convert these map distances to ground distances: 6 cm on a 1:25,000 map, 6 cm on a 1:50,000 map, and 3.2 cm on a 1:50,000 map. Give each answer in metres and in kilometres, and say why the first two answers differ.

→ Solution

EXERCISE 2

Take any printed or online map. Write down its scale, its edition or survey date, and the meaning of five symbols from the legend. Then name two things on the ground that the map might not show.

→ Solution

EXERCISE 3

Write a short program or spreadsheet formula that turns a map distance in centimetres and a scale number into kilometres. Test it with 8 cm at 1:25,000 and 8 cm at 1:50,000, then add a second function that does the reverse: how many centimetres on the map for a given ground distance.

→ Solution

Quick Reference

- **Scale:** ground distance = map distance x scale number
- **1:25,000:** 1 cm = 250 m, 4 cm = 1 km
- **1:50,000:** 1 cm = 500 m, 2 cm = 1 km
- **Colours:** blue water, green woodland, brown contours, black detail
- **Always check:** the legend and the edition date
- **North:** grid, magnetic and true north differ slightly

Coming next

Chapter 2 introduces grid references: how to turn a point on the map into a short number code that anyone with the same map can find.

Map Reading and Navigation

Course 1 · Chapter 2 · Grid References: Naming Any Place with Numbers

Describing a place in words ("the stile past the second farm") only works if both people know the area. A grid reference describes a place with a short number code that anyone holding the same map can decode. This chapter explains the grid, the rule for reading eastings before northings, and how to write and read four-figure and six-figure references. The examples follow the British National Grid used on Ordnance Survey maps; other countries use similar systems with different numbering (check the key of your own map).

The Grid

Printed over the map is a network of thin lines forming squares. Each line has a number printed on the map edge. On most walking maps the lines are 1 km apart, so each square is 1 km by 1 km on the ground. That is why the grid also helps with distance: two lines are always the same distance apart, however the paper is folded.

Eastings

The vertical lines. Their numbers rise as you move east (to the right). They are labelled along the top and bottom edges.

Northings

The horizontal lines. Their numbers rise as you move north (up the page). They are labelled along the left and right edges.

Grid square

The box between four neighbouring lines. A four-figure reference names one whole square.

Tenths

Splitting a square into ten parts in each direction lets you name a point within 100 m at 1:25,000 or 1:50,000.

Eastings First

Always give the easting (the number along the bottom) before the northing (the number up the side). The classic memory aid is **"along the corridor, then up the stairs"**: you walk along before

you climb. Reversing the two numbers names a different place, often many kilometres away, so this is the single most important habit in the chapter.

> **Numbers in the wrong order**
>
> The references 3472 and 7234 are two different squares. If you are reporting a position to someone (including the emergency services), say the order out loud: "easting 34, northing 72".

Four-Figure References

A four-figure reference names a whole square. Take the number of the vertical line on the **left** (west) side of the square, then the number of the horizontal line on the **bottom** (south) side. Join the two pairs into four digits.

Step	What you do	Example
1	Find the square that holds the feature	A church
2	Read the easting of the line on its left	34
3	Read the northing of the line along its bottom	72
4	Write easting then northing	3472

A four-figure reference is quick, but a 1 km square is large: a farm, a wood and a road junction might all sit in one square. It tells you where to look, not which feature you want.

Six-Figure References

To pin a point to within about 100 m, imagine the square divided into a 10 by 10 set of smaller boxes. Estimate how many tenths across the point lies from the left line, and how many tenths up from the bottom line. Then slot each tenth in after the matching two-digit line number.

```
# Square with left line 34 and bottom line 72.
# The church is about 6 tenths across and 3 tenths up.
```

```
easting  = "34" + "6"   # 346
northing = "72" + "3"   # 723
grid_ref = easting + northing  # 346723
```

Read the six figures as two halves: the first three are the easting, the last three are the northing. So 346723 means easting 346, northing 723. The third digit of each half is the tenth you estimated.

> **A romer saves guessing**
>
> A romer is a small printed or plastic scale with tenth marks at the map's scale. Place its corner on the point and read the two tenths directly. If you have no romer, mark the edges of a piece of paper into ten equal parts (on a 1:25,000 map a 1 km box measures 4 cm, so each tenth is 4 mm; on a 1:50,000 map the box is 2 cm and each tenth is 2 mm).

Reading a Reference

To go from a reference to a place, reverse the steps. Take 351698: easting 351 means line 35 and one tenth to the east; northing 698 means line 69 and eight tenths to the north. Find the line 35, move one tenth right, find line 69, move eight tenths up, and look where the two meet.

Reference	Easting	Northing	Meaning
3472	34	72	Whole square, bottom-left corner at lines 34 and 72
346723	34 and 6 tenths	72 and 3 tenths	A point within about 100 m
351698	35 and 1 tenth	69 and 8 tenths	Near the top of square 3569

Letters and the Wider Grid

The two-digit line numbers repeat every 100 km. On the British National Grid, two letters in front of the numbers (such as **NT** for the area around Edinburgh) say which 100 km square you are in.

A full reference reads like "NT 346 723". Letters matter when you give a reference to someone far from the area, but for a day on one map you can usually leave them off if you say which map you are using.

```
# Splitting a six-figure reference back into parts
ref = "346723"
easting  = ref[:3]       # "346"
northing = ref[3:]       # "723"
line_e, tenth_e = easting[:2], easting[2]   # "34", "6"
line_n, tenth_n = northing[:2], northing[2] # "72", "3"
```

Common Mistakes

Mistake	Fix
Northing before easting	Along the corridor, then up the stairs
Using the line on the right or the top of the square	Always use the left and bottom lines
Counting tenths from the wrong side	Measure from the left line and the bottom line only
Treating 7 tenths as 0.7 of a different square	Tenths are digits 0 to 9, added after the two-digit line number
Reading the grid numbers off a different map	Line numbers differ from map to map, so check you are using the right sheet

Challenges

EXERCISE 1

A square has its left line numbered 52 and its bottom line numbered 08. Write the four-figure reference for the square. Then write the six-figure reference for a point 4 tenths across and 9 tenths up in that square, and a second point 0 tenths across and 5 tenths up.

→ Solution

EXERCISE 2

Read these three six-figure references and describe each in words (line numbers and tenths): 218447, 603092, 470135. Then say how far, in kilometres, the first two squares' left and bottom lines are from each other if the grid lines are 1 km apart.

→ Solution

EXERCISE 3

Write a short program or spreadsheet formula that takes a six-figure reference as a string and returns the two line numbers and the two tenths. Then extend it to return the distance in metres between two references on a 1 km grid, assuming each tenth is 100 m. Test it with 346723 and 351698.

→ Solution

Quick Reference

- **Order:** easting (along) then northing (up)
- **Four figures:** left line then bottom line; names a 1 km square
- **Six figures:** add tenths after each line number; names a point within about 100 m
- **Reading:** first three digits easting, last three northing
- **Letters:** name the 100 km square; add them for far-away readers
- **Always:** use the left and bottom lines of the square

Coming next

Chapter 3 introduces contour lines: how a flat map shows hills, valleys and slopes so you can picture the shape of the land.

Map Reading and Navigation

Course 1 · Chapter 3 · Contours and Relief: Seeing the Shape of the Land

A paper map is flat, but the land is not. Contour lines are how a flat map describes hills, valleys and slopes, and learning to read them is what turns a map of lines into a mental picture of the ground. This chapter explains what a contour line is, how the interval and the spacing tell you height and steepness, and how to recognise summits, valleys, ridges and saddles.

What a Contour Line Is

A contour line joins all the points that are at the same height above sea level. Imagine the sea slowly rising around a hill: the shoreline at each stage would be a contour line. Walking along a contour line, you would neither climb nor descend.

Contour interval

The height difference between one line and the next. It is stated in the map key. Many walking maps use 10 m, and some detailed maps use 5 m (check the key of your own sheet).

Index contour

A thicker line, labelled with its height, that appears at regular steps (for example every fifth line) so you do not have to count from the sea.

Spot height

A single printed number (often with a dot) giving the exact height of a point such as a summit or road junction.

Relief

The overall shape and height variation of the land: its hills, valleys and slopes.

Reading Height

To find the height of a point, start from a labelled line and count. If the interval is 10 m and a thick line is labelled 200, the next thin line up is 210, then 220, and so on. A point lying between two lines is between those two heights; you can only estimate it unless a spot height is printed.

```
# Contours every 10 m, thick (index) line labelled 200 m.
index_height = 200
interval     = 10
lines_above  = 3              # counted up from the index line
height = index_height + lines_above * interval   # 230 m
```

Reading Steepness

The contours are always the same height apart (the interval), so how far apart they are on the map tells you how steep the ground is.

What you see	What it means
Lines close together	Steep ground: a lot of height gained over a short distance
Lines far apart	Gentle ground, or nearly flat
Evenly spaced lines	A steady, uniform slope
Lines close at the top, wide at the bottom	A slope that is steep high up and eases off (a concave slope)
Lines wide at the top, close at the bottom	A slope that is gentle high up and steepens (a convex slope), which hides the ground below from the top
Lines merge into one	A cliff or crag, where the ground is almost vertical

> **Putting a number on it**
>
> The gradient is the height gained divided by the ground distance covered. On a 1:25,000 map, 4 mm on paper is 100 m on the ground. With a 10 m interval, two lines 4 mm apart mean 10 m of climb in 100 m: a gradient of 10 percent, about 5.7 degrees. Lines 2 mm apart double that to 20 percent, about 11.3 degrees.

Landforms

Certain patterns of lines appear again and again. Once you know them you can read a whole landscape at a glance.

Feature	Pattern on the map	What it is on the ground
Summit	Closed rings, each higher than the one outside it, often with a spot height in the middle	The top of a hill
Valley	V or U shapes with the point of the V aiming uphill; a stream often runs along the bottom	Low ground between two higher areas
Ridge	V or U shapes with the point aiming downhill	A long line of high ground, with the land falling away on both sides
Saddle (col)	Two sets of higher rings facing each other with a gap between them	The low point on a ridge between two summits, and often the easiest crossing
Spur	A small ridge-like tongue of lines pointing downhill from a bigger hill	A rib of land running down the side of a hill
Depression	Closed rings with the heights falling towards the middle (tick marks point down)	A hollow or pit with no outlet

> **Valley or ridge?**
>
> Both give V shapes, so the direction of the point is not enough on its own. Check the numbers: if the lines to the point's side are higher, it is a valley; if they are lower, it is a ridge. Water is another clue. Streams run in valleys and never along the crest of a ridge.

Using Relief

Reading relief changes how you plan a walk. A route that looks short on the map may include a long, steep climb; a longer route round the contours may be faster and easier. Because water runs downhill, following a stream down a valley leads to lower ground and often to roads and villages, which is a useful safety idea when you are lost (check local advice before relying on it, since valleys can also hold cliffs and bogs).

```
# Total climb along a route, from heights read at checkpoints (m)
heights = [120, 150, 140, 190, 170]
climb = 0
for a, b in zip(heights, heights[1:]):
    if b > a:
        climb += b - a
print(climb)   # 30 + 50 = 80 m of ascent
```

Common Mistakes

Mistake	Fix
Assuming the interval is the same on every map	Read it in the key every time
Mistaking a ridge for a valley	Check which way the numbers rise and where the streams are
Judging steepness by the number of lines rather than their spacing	Close lines mean steep; many lines far apart can still be gentle
Forgetting small hills between the lines	A bump lower than the interval may not appear at all
Treating all hills as the same height because the shapes match	Always read the numbers

Challenges

EXERCISE 1

A map has a 10 m contour interval. Thick contours are labelled 150 and 200, with four thin lines between them. What is the height of the second thin line above 150? What is the height of the line directly above 200 and of the third line above 200? A path climbs from the 170 m line to the 230 m line: how many contour lines does it cross, counting both ends?

→ Solution

EXERCISE 2

Name the landform in each case. (a) Closed rings labelled 300, 310, 320, 330 from the outside inwards. (b) V-shaped lines labelled 100, 110, 120 with the points aiming towards the 120 side and a blue stream along the middle. (c) V-shaped lines labelled 100, 110, 120 with the points aiming towards the 100 side and no stream. (d) Two sets of rings reaching 400 m facing each other, with a gap at 350 m between them.

→ Solution

EXERCISE 3

Write a short program or spreadsheet formula that takes the contour interval (m), the spacing between two lines on the map (mm) and the map scale denominator (25000 or 50000), and returns the ground distance, the gradient as a percentage and the angle in degrees. Test it with 10 m, 4 mm, 1:25,000 and then 10 m, 2 mm, 1:50,000.

→ Solution

Quick Reference

- **Contour:** a line of equal height
- **Interval:** height between lines; read it from the key
- **Close lines:** steep; wide lines: gentle
- **Summit:** closed rings rising inwards
- **Valley:** points aim uphill, stream in the bottom
- **Ridge:** points aim downhill
- **Saddle:** low gap between two higher areas

Coming next

Chapter 4 introduces the compass: its parts, how bearings are measured, and the difference between grid north and magnetic north.

Map Reading and Navigation

Course 1 · Chapter 4 · The Compass: Direction You Can Measure

A map tells you what is around you; a compass tells you which way to go. The two together let you walk to a place you cannot yet see. This chapter introduces the baseplate compass, explains how directions are written as bearings from 0 to 360 degrees, and untangles the three different norths you will meet: true, grid and magnetic.

The Baseplate Compass

Walkers normally use a baseplate (or orienteering) compass: a clear plastic plate with a rotating housing and a magnetic needle inside. Its parts are worth learning by name.

Magnetic needle

A magnetised needle that swings to point towards magnetic north. The red end is the north end.

Rotating housing (bezel)

The ring around the needle, marked in degrees from 0 to 360 with the main points of the compass. You turn it to set a bearing.

Orienting arrow and lines

An arrow (often outlined) painted on the floor of the housing, with parallel orienting lines. You line the red needle up with it, so it works like a fixed north marker.

Direction-of-travel arrow

An arrow on the baseplate, pointing away from you. It shows the way to walk once the compass is set.

Index line

The mark at the base of the direction-of-travel arrow where you read the bearing off the housing.

Edge and scales

The straight edge of the plate has ruler scales (often for 1:25,000 and 1:50,000) for measuring distances and reading grid references.

What Is a Bearing?

A bearing is a direction written as the angle, measured clockwise from north, between north and the line you are interested in. A full circle is 360 degrees, so a bearing is always a number from 0 to 360, normally written with three digits and a degree sign, for example 045 degrees.

Direction	Bearing
North (N)	0 or 360 degrees
North-east (NE)	45 degrees
East (E)	90 degrees
South-east (SE)	135 degrees
South (S)	180 degrees
South-west (SW)	225 degrees
West (W)	270 degrees
North-west (NW)	315 degrees

The **back bearing** is the direction in which you would look back along the line you came. It is always exactly opposite: add 180 degrees to the bearing, or subtract 180 if the bearing is already above 180. It helps you check that you are not walking the wrong way.

```
# Back bearing: the opposite direction, kept inside 0-360
def back_bearing(bearing):
    return (bearing + 180) % 360

print(back_bearing(60))    # 240
print(back_bearing(300))   # 120
```

Three Norths

Unfortunately there is more than one north, and a navigator must know which one is meant.

North	What it is	Where you see it
True north	The direction of the geographic North Pole, where the lines of longitude meet	Used in astronomy and for long-distance navigation
Grid north	The direction of the vertical grid lines on the map (the northings run towards it)	All bearings you measure on the map are grid bearings
Magnetic north	The direction a compass needle points, towards the Earth's magnetic pole	All bearings you read in the field are magnetic bearings

Grid north and true north are close together over most of a map and can be ignored for walking. The one that matters is the gap between **grid north and magnetic north**, called the **magnetic variation** (or declination). It is printed in the map key together with the year it applies to, and with how fast it changes each year. It is not the same everywhere, and it changes slowly over time because the magnetic pole moves. In recent years the variation in much of Britain has been a small number of degrees west of grid north, but always read the figure for your own sheet (check).

> **Why it matters**
>
> A map bearing is measured from grid north; your compass needle points to magnetic north. If the two differ by 2 degrees and you ignore it, you drift sideways about 35 m for every kilometre walked. Over a long walk, or in mist, that is enough to miss a small target.

Converting Between Grid and Magnetic

When the magnetic variation is **west** of grid north (the common case in Britain in recent years, check your key), the rule is:

- **Grid to magnetic: add the variation.** (Mag is more, so grid to mag: add.)
- **Magnetic to grid: subtract the variation.**

If the variation is east the rules swap. Always wrap the answer back into the range 0 to 360. Many compasses have an adjustable declination scale that lets you build the correction into the setting so you do not have to do the arithmetic every time.

```
# Variation 2 degrees west of grid north
def grid_to_magnetic(grid, variation_w):
    return (grid + variation_w) % 360

def magnetic_to_grid(mag, variation_w):
    return (mag - variation_w) % 360

print(grid_to_magnetic(90, 2))   # 92
print(magnetic_to_grid(1, 2))    # 359
```

Keep it away from metal

Steel, magnets, phones, vehicles, power lines and even a belt buckle or a pocket knife can pull the needle off true. Hold the compass level, a little in front of you, and well away from metal. Check that the needle swings freely and settles before you read it, and that the red end is still the north end (compasses can be reversed by strong magnets).

Common Mistakes

Mistake	Fix
Following the needle instead of the direction-of-travel arrow	The needle only points to north; you walk where the travel arrow points
Ignoring the magnetic variation	Read the key and apply it, or use the compass's declination scale
Adding when you should subtract (or the reverse)	Note whether the variation is west or east, then apply the rule
Forgetting to wrap round 360	Add or subtract 360 so the answer lies from 0 to 360
Reading the needle near metal	Step away from metal objects and recheck
Using an out-of-date variation figure	Check the year printed in the key and allow for the yearly change

Challenges

EXERCISE 1

(a) Give the bearings of north, east, south, west and south-west. (b) Find the back bearing of 60, 300 and 175 degrees. (c) You are facing 350 degrees and want to face 020 degrees. Which way and how far do you turn by the shortest route?

→ Solution

EXERCISE 2

The magnetic variation is 2 degrees west of grid north. Convert (a) a grid bearing of 90 to magnetic, (b) a magnetic bearing of 90 to grid, (c) a grid bearing of 1 to magnetic, (d) a magnetic bearing of 1 to grid. Explain what you do when the answer is below 0 or above 360.

→ Solution

EXERCISE 3

Write a short program or spreadsheet that (a) turns a bearing into the nearest of the 16 compass points (N, NNE, NE ...), (b) gives the back bearing, and (c) converts grid to magnetic and magnetic to grid for a given westerly variation. Test it with bearings 0, 45, 100, 200 and 350, and with the conversions from Exercise 2.

→ Solution

Quick Reference

- **Bearing:** clockwise angle from north, 0 to 360 degrees
- **Back bearing:** add or subtract 180
- **Map bearings:** measured from grid north
- **Compass bearings:** measured from magnetic north

- **Variation west:** grid to magnetic add, magnetic to grid subtract
- **Always:** read the variation from the key, and keep metal away

Coming next

Chapter 5 puts the compass to work: taking a bearing from the map, setting it on the compass, following it on the ground, and taking a bearing from a landmark you can see.

Map Reading and Navigation

Course 1 · Chapter 5 · Taking Bearings: From Map to Ground and Back

Chapter 4 explained what a bearing is. This chapter uses one. You will learn to take a bearing from the map and carry it onto the ground, to follow it without wandering off line, and to do the reverse: take a bearing from a landmark you can see and turn it into a line on the map.

Map Bearing to Field Bearing

This is the everyday job: you are at point A, you want to reach point B, and you cannot simply see it. The compass is used first as a protractor on the map, then as a direction finder on the ground.

1. **Join the two points.** Lay the long edge of the compass baseplate along the line from A to B, with the direction-of-travel arrow pointing towards B. The map is not turned; you only need the edge of the plate.
2. **Set the housing to grid north.** Turn the rotating housing until the orienting lines inside it run parallel to the map's vertical grid lines, and the orienting arrow points to the top of the map (grid north).
3. **Read the grid bearing** at the index line.
4. **Convert to a field (magnetic) bearing.** With the variation west of grid north, add it; if east, subtract it (Chapter 4). Turn the housing to the new figure. (Or set the declination scale in advance, if your compass has one.)
5. **Take the compass off the map**, hold it level in front of you, and turn your whole body until the red end of the needle sits inside the orienting arrow ("red in the shed"). The direction-of-travel arrow now points at B.
6. **Pick a mark.** Look along the arrow to a clear feature on that line and walk to it.

> **Turn yourself, not the housing**
>
> Once the bearing is set, never touch the housing again until you have arrived. The only thing that turns is you. A common beginner mistake is to twist the housing until the needle looks right, which just resets the bearing to whatever way you happen to be facing.

```
import math

# Grid bearing between two points given as (easting, northing) in metres
def grid_bearing(e1, n1, e2, n2):
    return math.degrees(math.atan2(e2 - e1, n2 - n1)) % 360

print(round(grid_bearing(450, 200, 600, 350)))   # 45
print(round(grid_bearing(300, 300, 300, 100)))   # 180
```

The function takes the east-west difference first and the north-south difference second, because a bearing is measured from north, not from east as in school geometry. The final `% 360` turns a negative angle into its positive equivalent.

Following a Bearing

Holding the compass out and walking while staring at it is the worst way to follow a bearing: the needle swings, you wander, and you trip. Use the compass to choose a mark, then put it away and walk to the mark.

Pick a mark on the line

A rock, a tree, a gatepost, a patch of different grass: anything distinct and in line with the arrow. Walk to it by the easiest ground, not necessarily the straight line.

Keep legs short

An error of 2 degrees is about 35 m sideways per kilometre. Short legs reset the error each time you reach a mark.

Leapfrogging

In poor visibility, send a companion ahead to the edge of visibility and direct them onto your line with the compass. Walk up to them, then repeat.

Going around obstacles

Offset at right angles by a counted number of paces, pass the obstacle, then return by the same number of paces on the other side.

Sideways error	Over 500 m	Over 1,000 m
1 degree	about 9 m	about 17 m

Sideways error	Over 500 m	Over 1,000 m
2 degrees	about 17 m	about 35 m
5 degrees	about 44 m	about 87 m

Field Bearing to Map Bearing

The reverse job: you can see a landmark, perhaps a distinctive summit or a tower, and want to draw the line to it on the map.

1. Point the direction-of-travel arrow at the landmark.
2. Turn the housing until the red end of the needle is in the orienting arrow. Read the magnetic bearing.
3. **Convert to grid:** with variation west, subtract it; if east, add it.
4. With the housing set to the grid bearing, put a corner of the baseplate on the landmark on the map and pivot the whole compass until the orienting lines are parallel to the grid lines and the arrow points to the top of the map.
5. The plate edge now lies along the line between the landmark and the point you stand on. But you are looking *towards* the landmark, so you lie on the opposite side. To draw the line from the landmark back to yourself, use the **back bearing** (add or subtract 180).

```
# Variation 2 degrees west of grid north
def magnetic_to_grid(mag, variation_w):
    return (mag - variation_w) % 360

def back_bearing(bearing):
    return (bearing + 180) % 360

grid = magnetic_to_grid(128, 2)
print(grid)                 # 126
print(back_bearing(grid))   # 306
```

> **One bearing gives a line, two give a position**
>
> A single bearing only tells you that you are somewhere along a line. Taking bearings on two or three landmarks, and drawing each line, gives the point where they cross: your

position. Chapter 8 develops this properly (resection).

Common Mistakes

Mistake	Fix
Turning the map or the baseplate edge the wrong way round	The direction-of-travel arrow must point from start to destination
Orienting lines not parallel to the grid lines	Check along several grid lines, with the arrow pointing to the top of the map
Forgetting the variation (or applying it backwards)	Grid to magnetic and magnetic to grid use opposite signs
Twisting the housing while walking	Turn your body, never the housing
Using the forward bearing when you needed the back bearing	Ask: am I drawing a line from the landmark to me, or from me to it?
Long legs with no marks	Break the walk into legs that end at features you can see

Challenges

EXERCISE 1

The variation is 2 degrees west of grid north. Eastings and northings are in metres. Find the grid bearing, the magnetic bearing and the distance for each leg: (a) (450, 200) to (600, 350); (b) (300, 300) to (300, 100); (c) (700, 250) to (500, 450); (d) (100, 500) to (400, 100).

→ Solution

EXERCISE 2

With the same variation, you sight a landmark and read 128 degrees on the compass. (a) What grid bearing do you draw on the map? (b) What is the back bearing, in grid, from the landmark to you? (c) If you drift 3 degrees off a bearing over 800 m, how far off line are you? And 5 degrees over 500 m? (d) Why does walking in short legs to marks reduce the problem?

→ Solution

EXERCISE 3

Write a short program or spreadsheet that takes two points (easting, northing) and prints the grid bearing, distance and magnetic bearing for a given westerly variation, and a second function that returns the sideways drift for a given angle error and distance. Test it with the legs from Exercise 1 and the figures from Exercise 2.

→ Solution

Quick Reference

- **Map to ground:** edge along the route, orient to grid north, read, add variation (west), body turns "red in the shed"
- **Ground to map:** sight, red in the arrow, read, subtract variation (west), draw the line
- **Back bearing:** plus or minus 180, to draw the line from the landmark to you
- **Walking:** pick marks on the line, keep legs short, never twist the housing
- **Drift:** about 17 m per degree per kilometre

Coming next

Chapter 6 adds distance and time: measuring a route on the map, counting paces on the ground, and estimating how long a walk will take.

Map Reading and Navigation

Course 1 · Chapter 6 · Distance and Time: How Far, and How Long?

A bearing tells you which way to go. It does not tell you when to stop looking for the next feature, or whether you can finish before dark. This chapter adds the other half: measuring distance on the map, judging it on the ground by counting paces, and turning distance and climbing into an estimate of how long a walk will take.

Measuring Distance on the Map

Chapter 1 introduced scale. Measure the line with a ruler or the edge of the compass baseplate, then multiply by the scale. On a 1:25,000 map, 1 cm is 250 m; on a 1:50,000 map, 1 cm is 500 m. Many baseplates have ruler marks already matched to these scales (called romer or scale edges), so you can read the ground distance straight off.

Scale	1 cm on the map	4 cm on the map
1:25,000	250 m	1 km
1:50,000	500 m	2 km

Straight lines and bendy ones

A ruler gives the straight-line distance. Paths wind, so the distance you actually walk is longer. For a curving route, lay a piece of string or thread along it, following every bend, then straighten the string against the scale. Another way is to break the route into short straight sections, measure each and add them up.

> **Map distance is flat distance**
>
> The map shows distance along a flat plan. A steep slope is longer to walk than its map distance suggests. For most walking the difference is small, and Naismith's rule (below) deals with the climbing separately.

```
# Convert a measurement on the map (cm) to metres on the ground
def map_to_ground(cm, scale):
```

```
    return cm * scale / 100

print(map_to_ground(4.8, 25000))   # 1200.0 m
print(map_to_ground(6.4, 50000))   # 3200.0 m
```

The division by 100 converts centimetres into metres, since the scale ratio is the same in any unit but you want the answer in metres.

Pacing

On the ground there is no ruler, so you count steps. A **pace** here means a double step: you count each time the same foot lands. Walk a known distance, for example a measured 100 m, count your paces and repeat a few times to get an average. Many people take roughly 60 to 70 double paces per 100 m on level ground (check), but the only figure that matters is your own.

Know your number

Measure it on flat, firm ground. Write the figure on your map case or the back of your compass.

It changes

Uphill, rough ground, heavy rucksack or tiredness all shorten your stride, so you take more paces per 100 m. Downhill often lengthens it.

Keep count

Count in hundreds. A pebble in the pocket or a bead on a cord (a pacing bead string) moves one place for every 100 m so you do not lose your place.

Best for short legs

Pacing is most useful over short distances in poor visibility, to find a feature on a bearing: walk the bearing for 400 m and you should be there.

```
# Convert a pace count to metres, given paces per 100 m
def distance_from_paces(paces, per100):
    return paces / per100 * 100

print(distance_from_paces(130, 65))   # 200.0 m
print(round(distance_from_paces(320, 65)))   # 492 m
```

Naismith's Rule

Distance alone is a poor guide to time, because climbing is slow. **Naismith's rule** is a simple formula for walking time on hill ground, usually credited to the Scottish mountaineer William Naismith in the 1890s (check). In metric form:

- Allow **1 hour for every 5 km** walked (12 minutes per km).
- Add **10 minutes for every 100 m of ascent** (1 minute per 10 m).

Descent is not counted in the basic rule. Adjustments for steep descents (check) exist, and so does a refinement by Tranter that allows for fitness and load, but the basic rule is where everyone starts. It is deliberately simple and is for a fit adult walking steadily with a light pack. Slower groups, bad ground, snow or darkness all add time.

```
# Naismith's rule: minutes for a leg of "km" kilometres with "ascent_m" metres climb
def naismith(km, ascent_m):
    return km / 5 * 60 + ascent_m / 10

print(naismith(6, 300))    # 102.0  (72 for the distance + 30 for the climb)
print(naismith(8, 0))      # 96.0
```

> **Where does the climb come from?**
>
> Count it from the contour lines (Chapter 3): the height at the top of the leg minus the height at the bottom. If the route goes up and down several times, add up each separate climb, not just the net difference.

Breaks, and Being Honest About the Answer

Naismith's rule gives moving time. Stops for food, photos, map checks and rests are extra. A common habit is to add around 5 minutes per hour for breaks, or to take a longer lunch stop and add it separately. Whichever you use, write down your allowance and keep to it.

Then check the estimate against your own pace. If a walk takes you a third longer than the rule says every time, use a multiplier of 1.3 in your planning. A rule of thumb you adjust is more

useful than one you trust blindly. Chapter 7 uses these times to build a route card, and Chapter 9 uses them to decide when to turn back.

Common Mistakes

Mistake	Fix
Measuring a winding path with a straight ruler	Follow the bends with string, or measure in short straight sections
Using the wrong scale factor (25,000 vs 50,000)	Check the scale in the margin before multiplying
Counting every step instead of every second step, or mixing them	Decide once and stick to it; calibrate with the same method
Forgetting the climb in Naismith's rule	Work out height gained from the contours and add 10 minutes per 100 m
Leaving out breaks	Add a fixed allowance per hour and plan to it
Assuming the rule fits everybody	Time a few real walks and apply your own multiplier

Challenges

EXERCISE 1

Convert these map measurements to ground distances: (a) 4.8 cm on a 1:25,000 map; (b) 6.4 cm on a 1:50,000 map; (c) 3.2 cm on a 1:25,000 map; (d) a piece of string laid along a winding path measures 22 cm on a 1:25,000 map. Which of these would you expect a ruler to underestimate, and why?

→ Solution

EXERCISE 2

Using Naismith's rule (5 km/h plus 10 minutes per 100 m of ascent), find the time for: (a) 6 km with 300 m of ascent; (b) 10 km with 600 m of ascent; (c) 3.5 km with 150 m of ascent; (d) 8 km on level ground. Then, if you take 65 paces per 100 m, how far have you gone after 130 paces, and after 320 paces?

→ Solution

EXERCISE 3

A walk has three legs: 2.0 km with 120 m of ascent, 1.5 km on the flat, and 3.5 km with 380 m of ascent. Write a short program or spreadsheet that gives the moving time for each leg, the total, and the total with a break allowance of 5 minutes per hour. State the total distance and ascent.

→ Solution

Quick Reference

- **Map to ground:** cm on map x scale / 100 = metres (1:25,000 gives 250 m per cm; 1:50,000 gives 500 m per cm)
- **Winding routes:** string along the bends, or short straight sections added together
- **Pacing:** know your own paces per 100 m; expect more paces uphill, on rough ground and when tired
- **Naismith:** 12 minutes per km, plus 10 minutes per 100 m climbed
- **Breaks:** extra; add an allowance such as 5 minutes per hour

Coming next

Chapter 7 brings bearings, distance and time together: choosing a route, planning escape routes and writing a route card.

Map Reading and Navigation

Course 1 · Chapter 7 · Route Planning: Decide at the Kitchen Table

So far you have learned to read the map, find grid references, understand relief, use a compass and estimate distance and time. Route planning is where those skills combine. The best decisions are made before you set out, on a table, with a hot drink and plenty of time to think, rather than on a cold hillside when you are tired and the light is going.

Choosing a Route

Start with the group, not the map. A route that suits a fit pair on a long summer day may be wrong for a mixed group with children in October. Ask:

Who is going?

Fitness, experience and equipment. Plan for the slowest and least experienced person, not the strongest.

How much daylight?

Look up sunset for the day. Short winter days limit the distance far more than the map suggests.

What is the weather?

Check the forecast for the area and height you will be on, including wind and visibility, not just the town below.

What is the ground like?

Paths, open moor, rock, bog, rivers to cross. Rough or wet ground slows you and makes navigation harder.

Compare the options

There is rarely just one way. Sketch two or three, then compare them using the tools from earlier chapters: distance from the scale (Chapter 6), climbing from the contours (Chapter 3), and time from Naismith's rule. The shortest line is not always the quickest, and the quickest is not always the best.

Question	Where to look
How far is each option?	String or ruler against the scale

Question	Where to look
How much climbing?	Contours: add up every separate climb
How long will it take?	Naismith's rule, plus breaks
How easy is it to navigate?	Paths, walls, streams, ridges: lines you can follow
What could go wrong?	Steep ground, rivers, cliffs, exposed tops, long distances from help

Legs

Break the route into **legs**: short sections between clear points. A good leg is short enough to navigate without worry (often 1 to 2 km, less in poor visibility), runs from one identifiable feature to another, and has a single bearing or a single handrail along it. The ends of each leg are your checkpoints: a bridge, a path junction, a col, a spot height, a corner of a wall.

> **Choose checkpoints you cannot miss**
>
> A bridge, a junction of two paths or a lake is easy to recognise. A single contour on a featureless slope is not. Pick the kind of feature you will be sure of when you reach it.

Escape Routes

Every plan should have a way out. An **escape route** is a planned, easy way off the hill to safety if the weather turns, someone is injured or you are running late. Decide the escape routes at the planning stage and mark them on the map.

- Choose a route that drops quickly to lower, sheltered ground, ideally to a road or a track.
- Make it easy to navigate: a path, a stream to follow, a clear ridge.
- Avoid escape routes that cross steep ground, cliffs or big rivers.
- Note the bearing and distance at the points where you could use it.

An escape route is a safety plan, not a failure. Deciding in advance is what lets you use it calmly.

A Turn-Round Time

Some walks fail not on the map but on the clock: you keep going because the top is near, and end up descending in the dark. Set a **turn-round time** before you start: the latest time at which, wherever you are, you turn back. Work it out from your estimated return time and the time by which you must be down. Chapter 9 returns to this and to when to turn back for other reasons.

```
# Latest turn-round time, in minutes after midnight
def naismith(km, ascent_m):
    return km / 5 * 60 + ascent_m / 10

def clock(minutes):
    return f"{int(minutes // 60):02d}:{int(round(minutes % 60)):02d}"

down_by = 15 * 60 + 30             # must be down by 15:30
way_back = naismith(5, 0)       # 60 min by the basic rule
slow = way_back * 1.3 * (1 + 5 / 60)   # slow pace plus breaks
print(clock(down_by - slow))        # 14:06
```

The Route Card

A **route card** is a table that puts the plan on paper, one row per leg. It helps you navigate and keeps the plan in a form you can leave with someone else. A typical card has:

Column	What goes in it
Leg	From and to, with grid references
Bearing	Grid bearing from the map (field bearing is worked out on the spot: Chapter 5)
Distance	Kilometres for the leg
Ascent	Metres climbed on the leg
Time	Moving time from Naismith's rule, and the running total
Notes	Handrail, catching feature, hazards, escape route

Add the planned start time, the turn-round time, the expected finish time and the details of the group. Write the finish as an estimate with a margin, not as a promise. A route card with times

can also be calculated in code, which is how the exercises below work.

```
# Running arrival times down a list of legs
legs = [("Car park to bridge", 1.5, 40),
        ("Bridge to col", 2.5, 260)]

t = 9 * 60
for name, km, ascent in legs:
    t += naismith(km, ascent)
    print(name, clock(t))     # 09:22, then 10:18
```

Leave the Plan With Someone

Tell a responsible person where you are going, your route and escape routes, when you expect to be back, and when to raise the alarm if you are not (allow a margin past your return time). Tell them when you are safely down. Without that, a good plan helps no one but you.

> **A plan is not a promise**
>
> Conditions change. If the weather, the ground or the group does not match the plan, change the plan. The route card is there to help you decide, not to push you on.

Common Mistakes

Mistake	Fix
Planning for the strongest walker	Plan for the slowest and least experienced
Choosing the shortest line without checking the climb	Compare time, not just distance
Legs that are long or have no clear end point	Break them up at features you cannot miss
No escape routes, or ones over steep ground	Mark easy ways down at the planning stage
No turn-round time	Fix it before you start and keep to it

Mistake	Fix
Telling nobody	Leave the route, the times and the alarm time

Challenges

EXERCISE 1

You can reach the same point by Route A (6 km, 200 m of ascent) or Route B (4.5 km, 450 m of ascent). Use Naismith's rule to find the moving time for each. Which is quicker? Give one reason, other than time, why someone might still choose the other route.

→ Solution

EXERCISE 2

Write a short program that prints a route card timetable starting at 09:00 for four legs: Car park to bridge (1.5 km, 40 m ascent, bearing 80); Bridge to col (2.5 km, 260 m, bearing 35); Col to summit (1.0 km, 190 m, bearing 120); Summit to car park (5.0 km, 0 m, bearing 200). Show the arrival time for each leg, and give the total distance and ascent.

→ Solution

EXERCISE 3

An out-and-back walk starts at 09:30. The way out is 5 km with 400 m of ascent; the way back is 5 km with no counted ascent. Allow 5 minutes of breaks per hour. Find the finish time (a) at the plain Naismith pace, and (b) at 1.3 times that pace. If the group must be down by 15:30, what is the latest turn-round time at the slower pace?

→ Solution

Quick Reference

- **Plan for the group:** the slowest and least experienced person sets the pace
- **Compare options:** distance, climb, time, ease of navigation and hazards
- **Legs:** short sections between checkpoints you cannot miss
- **Escape routes:** easy ways down, chosen and marked in advance
- **Turn-round time:** fixed before you start, and kept
- **Route card:** leg, bearing, distance, ascent, time, notes; leave a copy with someone

Coming next

Chapter 8 covers what to do when the plan and the ground disagree: finding your position when you are not sure where you are.

Map Reading and Navigation

Course 1 · Chapter 8 · Finding Your Position: When the Plan and the Ground Disagree

Everyone is unsure of their position sooner or later. The skill is not never being lost; it is noticing early, stopping, and working out where you are before you make it worse. This chapter covers three tools: relocating by matching map to ground, resection with bearings, and building a plan that makes losing your position unlikely in the first place.

First: Stop and Think

The moment you are not sure, stop walking. Walking on in the hope that something familiar turns up is how a small error becomes a large one. Then work through these steps in order:

1. **Stop** and tell the group. Do not carry on while you work it out.
2. **Go back to your last certain point**: the last checkpoint you were sure of.
3. **Estimate how far you have come** since then, from the time walked and your pace (Chapter 6), and the direction you have been heading.
4. **Look for features** and match them to the map.
5. If that is not enough, **take bearings** (resection, below).
6. If you still cannot say where you are, **go back** to the last known point or to a handrail you can trust.

Relocation: Matching Map to Ground

Relocation means working out where you are from what you can see, without a compass. Set the map to match the ground (turn it until the map's north points to north, or until the map's features line up with the ones in front of you) and then compare.

Big features first

Hills, valleys, lakes, forests and large changes of slope are easier to match than small details.

Slope under your feet

Are you on a ridge, a spur, in a valley, on a shelf? Chapter 3's contour shapes tell you which ones the map allows.

Linear features

Point features

Paths, walls, fences, streams and power lines. Which one are you next to, and which way does it run?	A building, a sheepfold, a crag, a lone tree. Small, but each one can narrow the area a great deal.

Then narrow it down: "I am on a path (so I am on this line), the ground slopes down to my left (so I am on this side of the ridge), and I can see a stream ahead (so I am between these two points)." Each clue removes part of the map. When the clues all agree on one spot, you have relocated. If they disagree, one of them is wrong. Re-check the one you are least sure about.

> **Check, do not assume**
>
> It is easy to see what you expect to see. Look for one more feature that should be there if your guess is right, and one that should not be. If the first is there and the second is not, you can have more confidence.

Resection: Fixing Your Position With Bearings

If you can see two or three identifiable features on the ground and the map, you can fix your position with a compass. This is **resection**. It is the reverse of following a bearing: instead of taking a bearing from the map and walking along it, you take a bearing on the ground and draw it back on the map.

The method

1. Pick two or three features that you can identify on both the ground and the map, spread well apart, ideally at about 90 degrees to each other (not nearly in the same direction).
2. Point the direction-of-travel arrow at the first feature and turn the housing until the needle is in the orbit: this is your **field (magnetic) bearing** to the feature.
3. Convert it to a **grid bearing** by subtracting the magnetic variation (Chapter 4; the sign rule depends on whether the variation is west or east, so check the map).
4. Find the **back bearing**: the direction from the feature to you, which is the grid bearing plus or minus 180 degrees.
5. Place the compass on the map with its edge through the feature, line up the grid lines with the orienting lines, and draw a line along the back bearing from the feature, in the direction towards you.

6. Repeat for the second feature. You are where the two lines cross.
7. With a third feature, the three lines usually make a small triangle (a "cocked hat"). Your position is inside it. The smaller the triangle, the better your readings.

Back bearings

A back bearing is the bearing in the opposite direction. Add 180 degrees if the bearing is under 180, and subtract 180 if it is 180 or over. A wrap-around with modulo handles both cases at once.

```
# Back bearing: the opposite direction
def back(bearing):
    return (bearing + 180) % 360

print(back(45))     # 225
print(back(300))    # 120
print(back(180))    # 0
```

> **The classic slip**
>
> The bearing you measure points from you to the feature. The line you draw on the map runs from the feature to you. Forgetting to reverse the bearing puts your fix on the wrong side of the feature, which is far worse than a rough position.

Working the same thing out in code

The map method is geometry: two lines cross at a point. Using eastings and northings in metres from the grid (Chapter 2), a feature at (E, N) with back bearing b puts you at (E + t sin b, N + t cos b) for some distance t. Two features give two such lines; solving for where they meet gives your position.

```
import math

def resect(a, bearing_a, b, bearing_b):
    # a and b are (easting, northing) in metres
    ra = math.radians(back(bearing_a))
    rb = math.radians(back(bearing_b))
```

```
    da = (math.sin(ra), math.cos(ra))
    db = (math.sin(rb), math.cos(rb))
    det = da[0] * -db[1] + db[0] * da[1]
    rx, ry = b[0] - a[0], b[1] - a[1]
    t = (rx * -db[1] + db[0] * ry) / det
    return a[0] + t * da[0], a[1] + t * da[1]

print(resect((2800, 2300), 45, (2900, 900), 124))
# about (2004, 1504): within a few metres of (2000, 1500)
```

The small difference from the true position is down to rounding the bearings to whole degrees. In the field, the error is bigger: a compass is good to a degree or two at best, and a feature a kilometre away turns one degree into about 17 metres. Resection fixes your position to a small area, not a point.

Choosing features for a good fix

Choice	Why
Features about 90 degrees apart	The lines cross cleanly. Two features in nearly the same direction give lines that overlap, and a long, vague crossing.
Features close to you	A small angular error matters less over a short distance.
Features you are certain about	A wrong feature gives a wrong fix with no warning. A third bearing exposes it.
Sharp, distinct features	A summit or a building is a point; a broad hillside is not.

If you are on a linear feature

If you know you are on a path, stream or ridge but not where along it, one bearing is enough. Take a bearing to a known feature, draw the back bearing from it, and your position is where that line crosses the path.

Handrails and Catching Features

The best way to cope with losing your position is to plan so that it matters less. Two ideas from Chapter 7's legs help here.

Handrail

A linear feature you can follow, such as a wall, a stream, a fence or a path, that runs roughly the way you want to go. Keep it beside you and it keeps you on line.

Catching feature

A large feature beyond your target that you cannot walk past without noticing: a road, a stream across your line, a wall. It tells you that you have overshot.

Attack point

An easy-to-find feature near a hard-to-find target. Navigate to the attack point first, then take a short, careful leg to the target.

Aiming off

Deliberately aiming to one side of a target on a linear feature, so you know which way to turn when you reach it.

A catching feature is most useful with a limit: decide beforehand how far you should have walked, by time or by paces, and what to do if you reach that distance and have found nothing. This is simply Chapter 6's pacing and timing used as a safety net.

```
# Pacing limit for a leg
def paces(metres, per_100m):
    return round(metres / 100 * per_100m)

leg = 800
print(paces(leg, 60))              # 480 expected
print(paces(leg * 1.2, 60))        # 576: stop and think by here
```

Put It Together

Suppose you have been walking along a bearing in mist for twenty minutes and a wall that should have appeared has not. Stop. Compare your elapsed time and pace with the leg length. If you are still within the expected distance, you may simply be slow; if you are past the limit, you have probably veered off or miscounted. Go back to your last certain point, or if you can see anything identifiable, take bearings. Use the nearest handrail to get back on a line you trust, rather than guessing a new one.

Common Mistakes

Mistake	Fix
Walking on while unsure	Stop at once and return to the last certain point if needed
Forgetting the back bearing	Bearings from you to the feature must be reversed before drawing
Skipping the variation conversion	Field bearings must be changed to grid bearings before use on the map
Two features in nearly the same direction	Choose features about 90 degrees apart
Fitting the map to a guess	Look for something that should and should not be there to test the guess
No limit on a leg	Set a pace or time limit, and decide what you will do at it

Challenges

EXERCISE 1

Write a function `back(bearing)` that returns the back bearing, and use it to print the back bearing for each of these grid bearings: 45, 124, 300, 180, 0 and 359. Explain in one line why the modulo operator works for both small and large bearings.

→ Solution

EXERCISE 2

Feature A is at easting 2800, northing 2300 (metres, local grid) and Feature B is at 2900, 900. You measure grid bearings of 45 degrees to A and 124 degrees to B. Write a program that finds your position by resection and prints it to the nearest 10 m. Then show what happens to the answer if the bearing to B is wrong by 5 degrees (129 instead of 124).

→ Solution

EXERCISE 3

A leg is 900 m long and you walk 62 double paces per 100 m. A road (a catching feature) crosses your line 300 m beyond the target. Write a program that prints (a) the expected number of paces to the target, (b) the number of paces at which you should stop and think if you have not reached it (120% of the leg), and (c) the number of paces at which you would reach the road. Is the 120% limit before the road?

→ Solution

Quick Reference

- **When unsure:** stop, go back to your last certain point, estimate distance, match features
- **Relocation:** match big features first, then slope, then linear and point features; test your guess
- **Resection:** bearing to feature, convert to grid, reverse it, draw from the feature; position is where the lines cross
- **Back bearing:** add or subtract 180 degrees (or `(b + 180) % 360`)
- **Good fixes:** features about 90 degrees apart, close, certain, and three if possible
- **Handrails and catching features:** follow a line, stop at a feature you cannot miss, and set a pace or time limit

Coming next

Chapter 9 covers poor visibility and darkness: how the techniques change, what the safety margins are, and when the right decision is to turn back.

Map Reading and Navigation

Course 1 · Chapter 9 · Bad Weather and Night: Navigating When You Cannot See

Everything so far works best when you can see the landscape. When mist, rain, snow or darkness takes the view away, you fall back on the compass, your pacing and your timing, and you make everything smaller and slower. This chapter covers how the techniques change, what margins to build in, and the hardest skill of all: deciding to turn back.

What Changes When You Cannot See

In good visibility you navigate by looking: you pick a feature in the distance and walk to it. In poor visibility the distant features vanish and you can only trust what is in the next few metres. Three things change:

Legs get shorter

Each leg ends at a feature you can reach and recognise within the visibility you have. Long legs let small errors grow.

Instruments take over

The compass sets direction, pacing counts distance (Chapter 6), and a watch checks both. Your eyes confirm, they do not lead.

Everything is checked

Each leg is confirmed against a feature at its end: a slope change, a stream, a wall. If the feature does not appear, you stop.

Margins grow

Speed drops, so allow more time. Plan to be off the high ground earlier. Make the turn-back time earlier.

Walking a Bearing in Poor Visibility

You still take a bearing from the map (Chapter 5), but you cannot walk to a distant mark. The standard answer is a pair of people, or one person and an object, working as a team.

Leapfrogging

1. The navigator takes the bearing and sets the compass.
2. A second person walks ahead, just inside the visibility limit, and stops.

3. The navigator directs them left or right until they stand exactly on the bearing line.
4. The navigator walks up to them, passes them, and the process repeats with the roles swapped.

On your own, pick a small object on the bearing line (a rock, a tuft of grass) within sight, walk to it, and then pick the next one. Never walk looking at the compass: you drift sideways without noticing. Look up, find a mark, then walk to it.

> **Whiteout and flat light**
>
> In snow or heavy cloud there may be no contrast at all, and the ground can seem to merge with the sky. Leapfrogging still works, but your sense of slope fails, so a step can come as a surprise. Move slowly and check the ground before each step.

Why short legs matter

A small bearing error produces a sideways drift that grows with distance. If the error is e degrees, then over distance d you drift by d times tan(e).

```
import math

def drift(distance, error_deg):
    return distance * math.tan(math.radians(error_deg))

for d in (100, 200, 400):
    print(d, round(drift(d, 5)))
# 100 9
# 200 17
# 400 35
```

A 5 degree error is 9 m off line after 100 m, but 35 m after 400 m. If you can only see 30 m, a 400 m leg could take you past your target without a glimpse of it. A sensible rule is that a leg should end at something you will certainly see, and be short enough that the likely drift is smaller than the visibility.

Timing, Pacing and Checking

Each leg has an expected number of paces and an expected time (Chapter 6). In poor visibility conditions, add a margin because you walk more slowly and your pace gets shorter on rough or wet ground. Then use them as a check, not as a trigger to keep going:

- Count paces in hundreds, using pacing beads or a tally on your fingers.
- Note the time at the start of each leg.
- If the paces or time run out before you reach the feature, stop. Do not walk on hoping.
- Go through the relocation steps from Chapter 8 if you cannot find the feature.

Choose targets that are large or linear (a stream, a wall, a path), or use catching features. A single small cairn in mist is easy to walk past; a long wall across your line is not.

Night Navigation

Darkness has many of the same effects as mist, but there are extra points.

Issue	What to do
Reading the map	Use a head torch with a red or dimmed setting, which preserves your night vision. Cover the light when looking up.
Torch beam	A beam at your feet makes everything beyond it seem darker. Walk slowly and stop to look, using the torch only when needed.
Distances	They are hard to judge, and your pace is slower, so rely on timing and counted paces.
Features	Skylines and large shapes show at night; fine detail does not. Plan using big, simple features.
Spares	Carry a spare torch and batteries. A failed light with no spare turns a hard walk into an emergency.
Route choice	Prefer paths and handrails. Avoid steep slopes, crags and rough ground you cannot judge.

Safety Margins

Good navigators do not rely on being right; they rely on having room to be wrong. Build in margins before you start:

Time margin

Work out when it gets dark and when you must set off back, and add a margin on top for delays.

Escape routes

Know the quickest way down from each part of the route (Chapter 7) before you need it.

Kit

Spare warm layers, waterproofs, food, drink, torch, whistle, map and compass. A phone is a backup, not a navigation plan.

Someone knows

Leave your route card with someone who will raise the alarm if you are late.

The turn-back time is worked out in advance from when it gets dark, how long the return will take, and a margin.

```
def to_min(t):
    h, m = t.split(":")
    return int(h) * 60 + int(m)

def to_clock(mins):
    return f"{mins // 60:02d}:{mins % 60:02d}"

def turn_back_time(dark, remaining_min, margin=30):
    return to_clock(to_min(dark) - remaining_min - margin)

print(turn_back_time("16:30", 150))        # 13:30
print(turn_back_time("16:30", 150, 60))    # 13:00
```

When to Turn Back

Turning back is not failure; it is part of the plan. The summit, the viewpoint or the finish will still be there another day. Decide your criteria in advance, because on the hill, tired and close to the goal, judgement is at its worst. Common reasons to turn back:

- You have reached your turn-back time.
- The visibility has dropped below the minimum you can navigate safely.
- The weather is worse than forecast, or getting worse fast (wind, cold, rain, ice).
- Someone in the group is cold, exhausted, injured or unhappy.
- You are unsure of your position and cannot fix it.
- The route is not as you expected, and the alternatives are not clearly safe.

> **The group sets the pace**
>
> The weakest or least confident member is the limit for the whole group, not the strongest. If anyone wants to turn back, take it seriously and listen to why.

```
def decide(now, turn_back, visibility, min_vis, group_ok):
    reasons = []
    if to_min(now) >= to_min(turn_back):
        reasons.append("past turn-back time")
    if visibility < min_vis:
        reasons.append("visibility below minimum")
    if not group_ok:
        reasons.append("a member is struggling")
    if reasons:
        return "TURN BACK: " + ", ".join(reasons)
    return "Continue"

print(decide("12:50", "13:20", 60, 30, True))   # Continue
print(decide("13:25", "13:20", 60, 30, True))   # TURN BACK: past turn-back time
```

Turning back safely uses the same skills: go back along a route you know, using the handrails and catching features you already identified. If you have to turn back in poor visibility, a reverse bearing (Chapter 8's back bearing) along your outward route is often the safest way home.

Put It Together

Imagine setting out in a forecast of cloud lifting later. By midday the cloud is down and you can see 40 m. You are on a bearing with a leg of 350 m to a stream. You halve the leg by choosing an intermediate mark, leapfrog along the bearing with a partner, and count paces. At the pace

you expected the stream has not appeared; you stop, check the time against your turn-back time (not yet reached), and relocate using the slope under your feet and the direction of the wind. The stream appears 60 m to the left: you had drifted. You note the error, correct for it, and decide to shorten the next legs. Nothing dramatic happened because the margins were in place.

Common Mistakes

Mistake	Fix
Long legs in mist	Shorten legs to a feature you will certainly see and reach
Walking while staring at the compass	Take the bearing, pick a mark on it, look up and walk to the mark
Walking on past the pace or time limit	Stop and relocate when the limit is reached
Deciding the turn-back time on the hill	Set it before you start, from when it gets dark
No spare light	Carry a spare torch and batteries
Pressing on because the goal is close	Stick to the criteria you set earlier

Challenges

EXERCISE 1

Write the functions `to_min`, `to_clock` and `turn_back_time(dark, remaining_min, margin=30)`. It gets dark at 16:10 and the return to the road needs 140 minutes. Print the turn-back time with a 30 minute margin, and again with a 60 minute margin.

→ Solution

EXERCISE 2

Write a function `drift(distance, error_deg)` and print a table of the drift for errors of 2, 5 and 10 degrees over 100 m and 300 m. Then work out the longest leg for which a 3 degree error stays within 30 m of visibility, and say in one line why you would still use a shorter leg.

→ Solution

EXERCISE 3

Write a function `decide(now, turn_back, visibility, min_vis, group_ok)` that returns "Continue" or "TURN BACK:" followed by every reason that applies. Test it with three cases: all fine at 12:50 (turn-back 13:20, visibility 60, minimum 30); 13:25 with otherwise fine conditions; and 12:50 with visibility 20 and a struggling group member.

→ Solution

Quick Reference

- **Poor visibility:** short legs, instruments lead, confirm every leg, bigger margins
- **Leapfrogging:** a partner stands on the bearing line; walk to a mark, then the next, never staring at the compass
- **Drift:** distance times tan(error); long legs magnify small errors
- **Limits:** count paces and time; stop and relocate when the limit passes
- **Night:** dimmed or red light, spare torch, simple features, paths and handrails
- **Turn-back time:** dark minus return time minus margin, set before you start
- **Turn back when:** time is up, visibility too low, weather worse, someone struggling, or position unknown

Coming next

Chapter 10 is the capstone: you will plan a full day walk using every skill from the course, from the route and the time budget to the escape routes, the route card and the turn-back criteria.

Map Reading and Navigation

Course 1 · Chapter 10 · Plan a Day Walk: Capstone

This is the final chapter. There is nothing new to learn; instead you will use everything from the course to plan one complete day walk, step by step, the way an experienced walker does at the kitchen table the evening before. A good plan is what makes the day itself calm.

The Planning Sequence

Work in the same order every time. Each step uses a chapter you have already met:

Step	Question	Skill from
1. Aim	Who is going, how fit are they, how long a day do you want?	Chapter 7
2. Route	What are the start, the turning points and the finish? Is the terrain suitable?	Chapters 1-3, 7
3. Legs	For each leg: grid references, distance, ascent, bearing	Chapters 2, 3, 5, 6
4. Time	How long does each leg take, and when do you arrive?	Chapter 6
5. Safety	Escape routes, catching features, hazards, weather, kit	Chapters 7-9
6. Limits	Turn-back time and the other reasons to turn back	Chapter 9
7. Record	Route card, shared with someone who will notice if you are late	Chapter 7

Our Worked Route

We will plan a round walk from a start point, out to a bridge, up to a col, on to a summit and back directly to the start. The map positions (in metres from the grid origin, with heights from the contours) are:

Point	Easting (m)	Northing (m)	Height (m)
Start	3000	5000	100
Bridge	5000	5000	100
Col	5000	8000	450
Summit	7500	9500	780

> **Remember**
>
> These are practice coordinates on an imaginary map. On a real map you would read six-figure references (Chapter 2) and convert them to metres in the same way. The return leg here is a straight line for simplicity; a real return would follow a path or valley you had checked on the map.

Legs, Bearings and Times

For each leg we need a grid bearing (Chapter 5), a distance, the ascent (Chapter 3) and a time from Naismith's rule (Chapter 6): 12 minutes per kilometre plus 10 minutes per 100 m climbed. The whole job is a short loop.

```
import math

def to_min(t):
    h, m = t.split(":")
    return int(h) * 60 + int(m)

def to_clock(mins):
    return f"{mins // 60:02d}:{mins % 60:02d}"

def bearing(e1, n1, e2, n2):
    return round(math.degrees(math.atan2(e2 - e1, n2 - n1)) % 360)

def naismith(dist_km, ascent_m):
    return round(dist_km * 12 + ascent_m / 100 * 10)
```

```
# name, easting (m), northing (m), height (m)
points = [
    ("Start",  3000, 5000, 100),
    ("Bridge", 5000, 5000, 100),
    ("Col",    5000, 8000, 450),
    ("Summit", 7500, 9500, 780),
    ("Start",  3000, 5000, 100),
]

clock = to_min("09:00")
total = 0
for a, b in zip(points, points[1:]):
    dist = math.hypot(b[1] - a[1], b[2] - a[2])
    ascent = max(0, b[3] - a[3])
    mins = naismith(dist / 1000, ascent)
    total += mins
    clock += mins
    print(f"{a[0]:>6} -> {b[0]:<6} {bearing(a[1], a[2], b[1], b[2]):03d} deg {dist:
print("Walking time:", total, "min")
print("With 45 min of stops:", total + 45, "min, back at", to_clock(to_min("09:00")

# Start -> Bridge 090 deg  2000 m +  0 m  24 min  09:24
# Bridge -> Col    000 deg  3000 m +350 m  71 min  10:35
#    Col -> Summit 059 deg  2915 m +330 m  68 min  11:43
# Summit -> Start  225 deg  6364 m +  0 m  76 min  12:59
# Walking time: 239 min
# With 45 min of stops: 284 min, back at 13:44
```

Read what the numbers tell you. The route is about 14 km with 680 m of ascent and takes roughly four hours of walking, finishing around 13:45 with stops. The long final leg is the biggest single item, and it is a straight-line estimate, so a real path would be longer. Real walkers add a margin for that.

Grid bearing to compass bearing

The bearings above are grid bearings. In the field you must adjust for the magnetic variation shown on your map (Chapter 4) before following one on a compass, adding or

subtracting as the map tells you. Write both columns on your route card so you do not have to calculate with cold hands.

Safety Planning

Escape routes

For each leg, note the quickest way down or out: a track from the col, the road at the bridge. Check that each is a real path on the map.

Handrails and catching features

Choose a stream, wall or ridge to follow on each leg, and a feature beyond each turning point that tells you that you have gone too far.

Hazards

Look for steep ground, crags, river crossings and open exposed tops on the map, and plan around them (Chapter 3).

Weather and kit

Check the forecast for the summit, not the valley. Pack the kit list from Chapter 9, plus a spare layer for the highest point.

The Time Budget and the Turn-Back Time

Compare the finish time with the light. Say it gets dark at 16:30 and you want a one hour margin. The latest you should be back is 15:30, so a 13:44 finish leaves a comfortable margin of nearly two hours. The latest safe start would be about 11:00.

```
def plan(start, legs, stops, dark, margin=60):
    walking = sum(naismith(d, a) for d, a in legs)
    finish = to_min(start) + walking + stops
    latest = to_min(dark) - margin
    status = "OK" if finish <= latest else "TOO LONG"
    return walking, to_clock(finish), status
```

Then set a fixed point-by-point turn-back time as in Chapter 9: for each turning point, the latest time you can arrive and still get home with the margin. If you reach the col at 12:30 when the

plan said 10:35, you are two hours behind and the summit is no longer sensible. Decide that now, at the table, not on the hill.

The Route Card

The route card turns the plan into a single page you can leave with someone. For each leg it holds the start and end points, the bearing, distance, ascent, time, expected arrival and the escape route. It also records the group, the vehicle, the kit, the planned finish and the time at which the person at home should raise the alarm.

```
def route_card(legs, start, escape):
    clock = to_min(start)
    print("From      To        Dist   Ascent  Time  Arrive  Escape")
    for name_a, name_b, dist, ascent in legs:
        mins = naismith(dist, ascent)
        clock += mins
        print(f"{name_a:<9} {name_b:<9} {dist:4.1f}   {ascent:5d}   {mins:4d}  {to_

legs = [("Start", "Bridge", 2.0, 0), ("Bridge", "Col", 3.0, 350), ("Col", "Summit",
escape = {"Bridge": "back to road", "Col": "south track", "Summit": "retrace to Col"
route_card(legs, "09:00", escape)

# From      To        Dist   Ascent  Time  Arrive  Escape
# Start     Bridge     2.0       0    24  09:24   back to road
# Bridge    Col        3.0     350    71  10:35   south track
# Col       Summit     2.9     330    68  11:43   retrace to Col
```

On the Day

- Check the forecast again before leaving. If it is worse than the plan allowed for, choose a lower route or stay home.
- Leave the route card with someone, and tell them when you are back.
- Set the map to the ground at each turning point (Chapter 1) and confirm with a feature, not just the time.
- Keep ticking off the card: note your actual arrival times against the plan.

- If you fall behind, change the plan early: skip the summit, take an escape route. Do not try to catch up by hurrying.
- When you finish, tell the person who has your card.

> **Review afterwards**
>
> Compare actual times with planned times. If you were consistently slower, your personal pace is slower than Naismith's rule; adjust future plans. This is how the rule becomes your own.

Common Mistakes

Mistake	Fix
Planning the route for the best walker	Plan for the slowest or least experienced person
Forgetting stops in the time budget	Add time for food, photographs and navigation checks
Trusting straight-line distances	Measure along the actual path and add a margin
Leaving grid bearings uncorrected	Apply the magnetic variation and write both on the card
No escape routes for the later legs	Check one for every leg before you set off
Fixing the turn-back time on the hill	Set it at the table, from the light and the return time
Telling nobody the plan	Leave the card, and agree when to raise the alarm

Challenges

> **EXERCISE 1**
>
> Write functions `bearing(e1, n1, e2, n2)` (rounded grid bearing in degrees, 0 to 359) and `distance(e1, n1, e2, n2)`. Use them on a three-leg route with corner points (1000, 2000), (4000, 6000), (4000, 9000) and back to (1000, 2000), printing the bearing and distance of each leg.

→ Solution

EXERCISE 2

Write `plan(start, legs, stops, dark, margin=60)` returning the walking time, the finish time and "OK" or "TOO LONG" against the time it gets dark less the margin. Use legs (3 km, 200 m ascent), (4 km, 400 m) and (5 km, 0 m), 45 minutes of stops, and dark at 16:30. Try starts of 09:00 and 13:00.

→ Solution

EXERCISE 3

Write `route_card(legs, start, escape)` that prints one line per leg with the names, distance, ascent, Naismith time, arrival time and escape route. Use the three legs and the escape notes from this chapter, starting at 09:00.

→ Solution

Quick Reference

- **Plan in order:** aim, route, legs, time, safety, limits, record
- **Each leg:** grid references, bearing, distance, ascent, time, escape route
- **Naismith:** 12 minutes per km plus 10 minutes per 100 m of ascent, then add stops
- **Bearings:** grid from the map, then correct for magnetic variation
- **Latest finish:** dark minus a margin; the turn-back times are set at the table
- **Route card:** left with someone, with a time to raise the alarm
- **On the day:** compare the plan with reality, change it early, tell people you are back

Course complete

You can now read a map, find a grid reference, understand relief, use a compass, take and follow bearings, estimate time and distance, plan a route, fix your position, cope with poor

visibility and plan a complete day. The next step is to practise: take a short, easy walk, navigate it deliberately, and build up from there.