ST. MARY'S SCHOOL

Algebra II

VOLUME 1

Modeling and Function Algebra



STUDENT REFERENCE

Mod 1 · Class meetings 1–25

Explain. Model. Make sense of the result.

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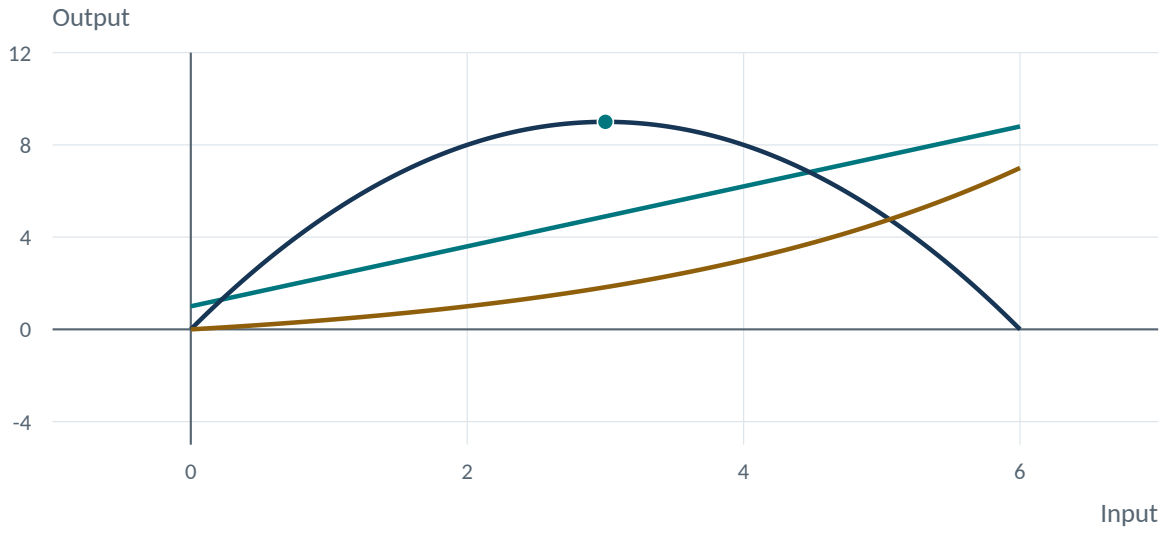
Algebra II

Volume 1

Modeling and function algebra

Student reference

Worked examples, graphs and short checks for the first mod of Algebra II. Use the lesson number in the outer margin to move between this book and the workbook.



Mod 1 | Class meetings 1 through 25

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1

LESSON 1

Functions describe quantities

A function connects an input to an output

In this lesson

Identify the quantities in a function, interpret its values, choose reasonable inputs and recognize the patterns behind three familiar function families.

A function assigns exactly one output to each allowed input. The input and output can represent measurements, counts or other quantities. Begin by naming them and their units.

The notation $f(3)$ means the output assigned to input 3. It does not mean f multiplied by 3. A formula is one representation; a table, graph or verbal rule can represent the same relationship.

EXAMPLE 1.W1 | Read a model in context

A school club has 24 dollars and earns 5 dollars per notebook sold. Let n be notebooks sold and $M(n)$ be the money in dollars. Find and interpret $M(7)$.

Solution

The rule is $M(n) = 24 + 5n$. The 24 is money already available; the 5 is dollars added per notebook.

Substitute the input: $M(7) = 24 + 5(7) = 59$.

After 7 notebooks are sold, the club has 59 dollars. The input is 7 notebooks; the output is 59 dollars.

Input: notebooks	0	1	2	7
Output: dollars	24	29	34	59

The ordered pair $(7, 59)$ puts the input first. On a graph, the horizontal axis would count notebooks and the vertical axis would show money.

Ask what the number means

Before calculating, name the requested quantity. After calculating, include its units. A correct number can still answer the wrong question.

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LESSON 1

1

Allowed inputs are part of the model

The **domain** is the set of allowed inputs. The **range** is the set of outputs actually attained. An algebraic expression may accept values that the situation excludes. Counts of whole objects are usually discrete; elapsed time and measured distance can often vary continuously.

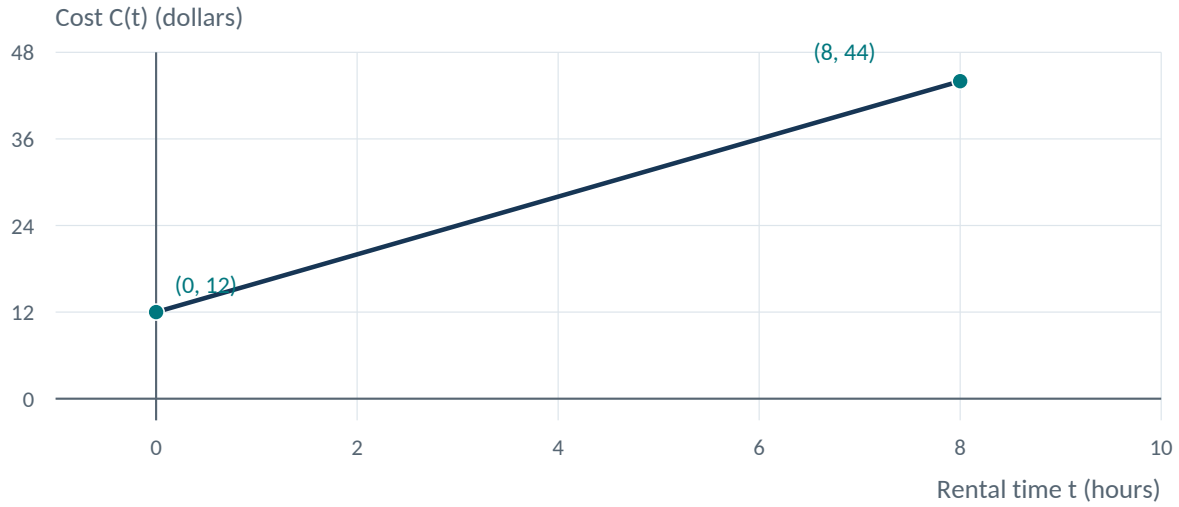
EXAMPLE 1.W2 | Separate a formula from its context

A rental costs $C(t) = 12 + 4t$ dollars for $0 \le t \le 8$ hours. Fractional rental times are allowed. Find $C(2.5)$ and decide whether 10 is an allowed input.

Solution

$C(2.5) = 12 + 4(2.5) = 22$ dollars. The input is allowed because 2.5 lies between 0 and 8.

The expression gives $C(10) = 52$, but the rental model applies only through 8 hours. That calculation does not establish a valid 10-hour rental charge.



The line segment includes all real inputs from 0 through 8. Filled endpoints mean the boundary values are included.

For this continuous rental model, the domain is $[0, 8]$ and the range is $[12, 44]$. A bracket includes its endpoint; a parenthesis excludes it. Thus $[0, 8)$ means $0 \le t < 8$, while $(0, 8)$ excludes both ends. An infinite endpoint always uses a parenthesis.

CHECK 1.C1

A van charges $F(n) = 10 + 3n$ dollars for a group of at most 12 passengers. Assume it can carry an empty group for the purpose of the model. State the domain and find $F(8)$. Is 8.5 allowed?

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LESSON 1

1

Recognize a useful family

Look for how outputs change as inputs change. Comparing differences or ratios makes sense only after checking the sizes of the input steps.

Family	Evidence over equal input steps
Linear	Roughly constant output differences, or roughly constant rates.
Quadratic	First differences change roughly linearly; a parabola has a single maximum or minimum over the real line.
Exponential	Roughly constant ratios of successive outputs.

EXAMPLE 1.W3 | Choose from a table

At inputs $0, 1, 2, 3$, the outputs are $3, 6, 12, 24$. Which family is a reasonable candidate?

Solution

The differences are $3, 6, 12$, so they are not constant.

The ratios are $6/3 = 2$, $12/6 = 2$ and $24/12 = 2$. Equal input steps multiply the output by 2, which supports an exponential model.

One matching rule is $f(x) = 3 \cdot 2^x$. The table supports this candidate; it does not prove how the process behaves outside the observations.

CHECK 1.C2

Equal input steps give outputs $4, 9, 14, 19$. Suggest a family and explain what evidence would make you reconsider it.

What to remember

A model is useful when its structure fits the situation. An increasing pattern can be linear, quadratic or exponential. “It goes up” is not enough to choose a family.

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LESSON 2

Average rate of change

Compare changes, not just outputs

In this lesson

Calculate average rate from a table, graph or formula. Interpret its sign and units, and connect it to the slope of a secant line.

Let $f(a)$ and $f(b)$ be the outputs at two different inputs a and b. Average rate of change compares the net output change with the input change.

$$\text{Average rate} = \frac{\text{change in output}}{\text{change in input}} = \frac{f(b) - f(a)}{b - a}, \qquad a \neq b$$

Keep the subtraction order consistent. If the output difference uses final minus initial, the input difference must use the same order. The units are output units per input unit.

EXAMPLE 2.W1 | Read a rate from a table

A tank contains 50 liters at minute 2 and 32 liters at minute 8. Find its average rate of change.

Solution

The net output change is $32 - 50 = -18$ liters. The input change is $8 - 2 = 6$ minutes.

The average rate is $-18/6 = -3$ liters per minute.

The tank loses an average of 3 liters per minute over this interval. The statement does not say that the drainage rate was identical at every moment.

CHECK 2.C1

A plant grows from 12 cm on day 1 to 30 cm on day 7. Find the average rate and interpret its units.

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LESSON 2

2

The same rate appears on a graph

A **secant line** passes through two points on a graph. Its slope is the function's average rate over that interval. The function itself may be curved between the points.

EXAMPLE 2.W2 | Connect the formula and secant

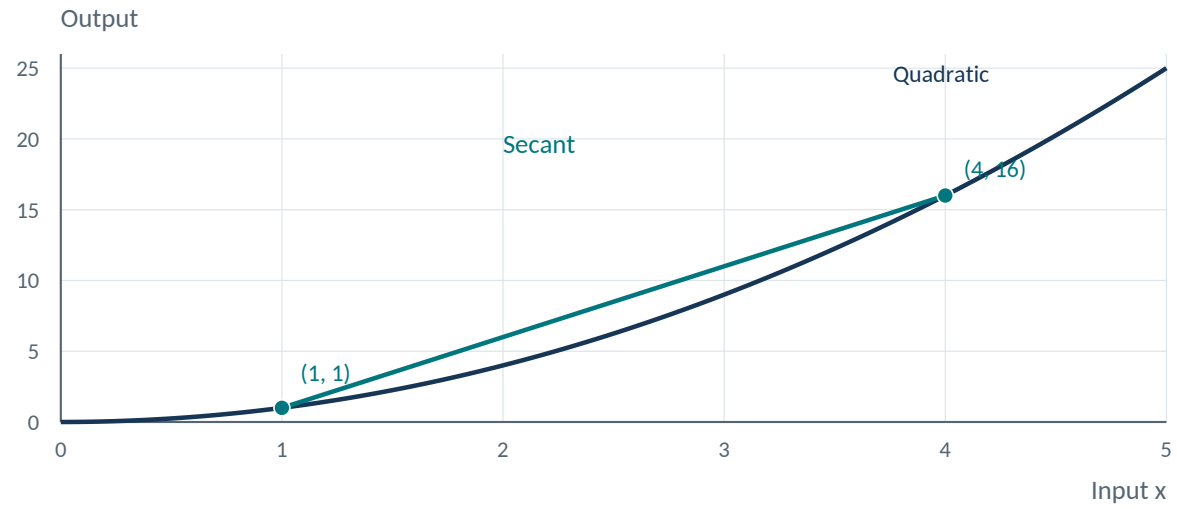
For $f(x) = x^2$, find the average rate from input 1 to input 4.

Solution

The endpoint outputs are $f(1) = 1$ and $f(4) = 16$.

The rate is $(16 - 1)/(4 - 1) = 15/3 = 5$.

The secant through $(1, 1)$ and $(4, 16)$ has slope 5. It has the same net rise and run as the curve over that interval.



The secant compares the endpoints. Its constant slope does not imply a constant slope along the parabola.

A common denominator error

The denominator is the input difference. It is not the final input by itself and not the number of observations in a table.

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LESSON 2

2

The sign tells you about change

A negative output and a negative rate mean different things. An output describes a value. A rate describes how one value changes relative to another.

EXAMPLE 2.W3 | Negative values can have a positive rate

The temperature is -6°C at 7 a.m. and 2°C at 11 a.m. Find the average rate.

Solution

The temperature change is $2-(-6)=8$ degrees Celsius. Four hours pass.

The rate is $8/4=2$ degrees Celsius per hour. It is positive because the temperature rises.

A rate of zero means zero net output change across the chosen interval. The output may still rise and fall between the endpoints.

CHECK 2.C2

An object is 3 meters high at 1 second and again at 5 seconds. Its height reaches 11 meters in between. Find its average rate from 1 to 5 seconds. Explain why zero does not mean the object stayed still.

Question	Quantity to calculate
What is the value at an input?	$f(a)$
How much did the output change?	$f(b)-f(a)$
How much change per input unit?	$\dfrac{f(b)-f(a)}{b-a}$

What to remember

Use both endpoint outputs, divide by the input change, and attach units. Then explain what the rate does and does not tell you.

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3

LESSON
3

Predict from a rate and a point

Use a known value as an anchor

In this lesson

Predict from a rate and an input-output pair. Distinguish an exact endpoint calculation from an estimate within or near a nonlinear interval.

Suppose you know the output $f(a)$ at input a and use a rate m. To predict the output at input x, first calculate how far the input moves from the anchor.

$$L(x) = f(a) + m(x - a)$$

L is the linear prediction rule. For a function known to be linear with rate m, it gives the exact model output. For a nonlinear function, it may be an estimate.

EXAMPLE 3.W1 | Move forward from the anchor

A tank contains 70 liters at minute 4 and fills at a constant 6 liters per minute. Find the volume at minute 9.

Solution

The input change is $9 - 4 = 5$ minutes. The output increases by $6(5) = 30$ liters.

The volume is $70 + 30 = 100$ liters. The anchor rule is $V(t) = 70 + 6(t - 4)$.

Using $70 + 6(9)$ would count nine minutes after the anchor, rather than five.

CHECK 3.C1

A linear model has output 18 at input 2 and rate 4. Find its output at input 7.

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LESSON 3

3

An average rate recovers its endpoint

If m is the actual average rate on $[a, b]$, then it was defined using both endpoint values. Multiplying it by the same interval width recovers the exact net change.

$$m = \frac{f(b) - f(a)}{b - a} \quad \Longrightarrow \quad f(b) = f(a) + m(b - a)$$

EXAMPLE 3.W2 | Separate an endpoint from an interior estimate

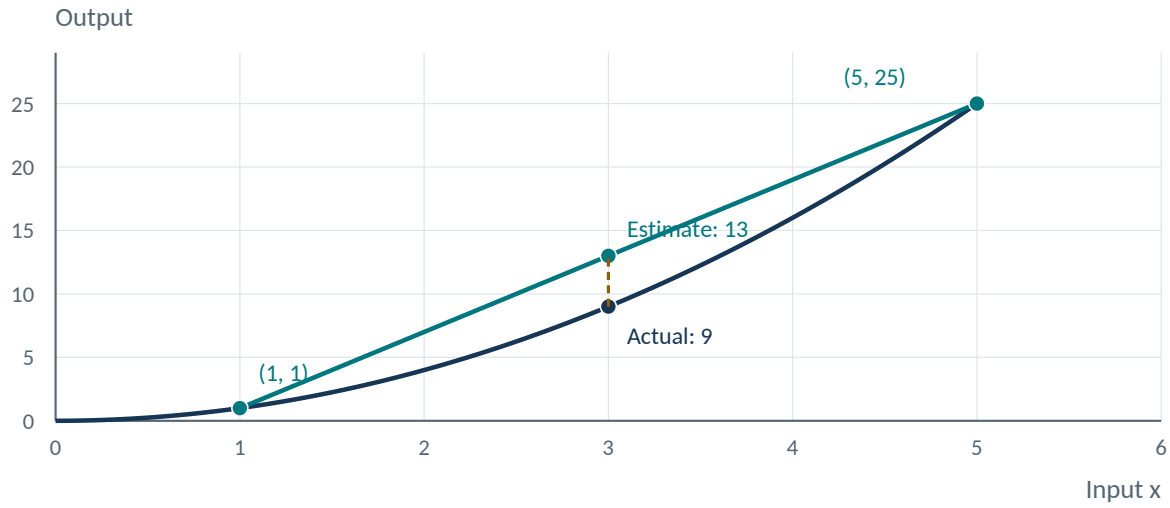
Use $f(x) = x^2$ on $[1, 5]$. Its average rate is 6. Start at $(1, 1)$ and predict the outputs at 5 and 3.

Solution

The rule is $L(x) = 1 + 6(x - 1)$. It gives $L(5) = 25$, exactly equal to $f(5)$.

At input 3, it gives $L(3) = 13$, while $f(3) = 9$. The interior prediction is an estimate, and it is 4 too high.

The exact endpoint result does not require a linear function. The exact interior result would require additional information.



The secant matches both endpoints. At the interior input 3, the secant and the quadratic have different outputs.

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LESSON 3

3

Check time direction, units and assumptions

EXAMPLE 3.W3 | Estimate after an observation

At noon a water level is 90 cm. Its average change over the preceding hour was -12 cm per hour. Estimate the level 15 minutes later.

Solution

Convert the input change to hours: $15/60 = 1/4$.

The estimate is $90 + (-12)(1/4) = 87$ cm.

This assumes the recent rate remains useful for the next 15 minutes. Past average change does not guarantee a future rate.

The same rule can move backward. If the output is 50 at input 6 and the function is linear with rate 3, then at input 2 it is $50 + 3(2 - 6) = 38$. A negative input change subtracts growth.

CHECK 3.C2

You know $f(0) = 2$ and the actual average rate on $[0, 4]$ is 5. Find $f(4)$, then give a linear estimate of $f(2)$. Which result is guaranteed?

Situation	Status of the prediction
Known linear function with its constant rate	Exact within the model.
Actual interval average used for the other endpoint	Exact endpoint recovery, even if the function is nonlinear.
Average rate used inside or outside that interval	Generally an estimate; state the assumption.

What to remember

Start with the known output. Multiply the rate by the change from the known input. Keep the time units consistent and label estimates honestly.

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LESSON 4

Build and interpret linear models

Construct a line from two observations

In this lesson

Build a linear model from two points or a rate and point. Interpret the slope and intercept, state a contextual domain and judge a prediction limit.

A linear function has a constant rate of change. Two different-input observations determine a line, but using that line as a model also requires a reason to expect roughly constant change.

EXAMPLE 4.W1 | Find the rate, then the rule

A print shop charges 26 dollars for 4 posters and 50 dollars for 10 posters. Assume a fixed setup fee plus a constant price per poster. Build the model.

Solution

The rate is $m = (50 - 26)/(10 - 4) = 24/6 = 4$ dollars per poster.

Use the known pair $(4, 26)$: $C(n) = 26 + 4(n - 4)$.

Expand: $C(n) = 4n + 10$. The model has a 10-dollar setup fee and a 4-dollar charge per poster.

$$C(n) - 26 = 4(n - 4) \qquad \text{and} \qquad C(n) = 4n + 10$$

The first is point-slope form. It displays a known point and the rate. The second is slope-intercept form. It displays the rate and the output at input zero.

CHECK 4.C1

A line passes through $(3, 17)$ with slope 4. Write an anchor-form rule and simplify it.

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LESSON 4

4

Interpret both coefficients

EXAMPLE 4.W2 | A negative intercept can make sense

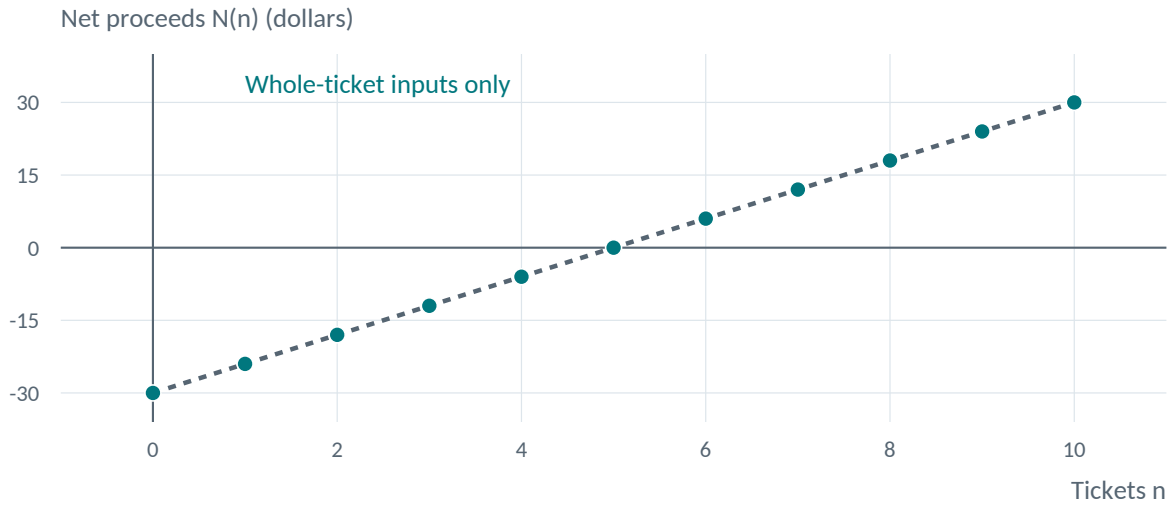
A fundraiser has a 30-dollar setup cost and receives 6 dollars per ticket sold. Let $N(n)$ be its net proceeds after selling n tickets, with capacity 50.

Solution

$N(n) = 6n - 30$. The rate is 6 dollars of net proceeds per ticket. The intercept is -30 dollars, representing the setup cost before any tickets are sold.

At 15 tickets, $N(15) = 90 - 30 = 60$ dollars. The contextual domain is the integers from 0 through 50.

Setting $N(n) = 0$ gives $6n - 30 = 0$, so the fundraiser breaks even after 5 tickets.



The mathematical line continues, but the ticket model uses whole-number inputs within the stated capacity. The displayed points show some allowed counts.

An intercept is the model output at input zero. Whether that input is physically meaningful or supported by observations depends on the context. Do not automatically call every intercept an observed starting value.

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LESSON 4

4

Check the model against its setting

EXAMPLE 4.W3 | Limit a model to a stated process

At minute 2, a tank holds 40 liters. From then on it drains at 5 liters per minute until empty. Construct the model for this stated period.

Solution

Anchor at the observed time: $V(t) = 40 - 5(t - 2) = 50 - 5t$.

Empty means output zero: $50 - 5t = 0$, giving $t = 10$. The contextual domain is $2 \leq t \leq 10$.

The intercept of 50 liters at minute 0 is a backward extrapolation. The statement did not establish the process before minute 2.

CHECK 4.C2

A model for a club order is $C(n) = 18 + 2n$ dollars, with at most 40 whole items. Include a zero-item order in this model. Interpret the coefficients, find the cost of 12 items and state the allowed inputs.

Before trusting a prediction

Check the input units, the allowed domain and the constant-rate assumption. A line through two observations is not evidence that a process remains linear at every distance or duration.

A good model explanation connects an equation to the quantities. It should say why the rate and initial value are reasonable, not merely report that the algebra works.

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LESSON 5

Read quadratic forms

Different forms reveal different features

In this lesson

Connect standard, factored and vertex forms of a quadratic. Select the form that reveals the requested feature, and use symmetry and differences to recognize quadratic behavior.

A quadratic function has standard form $f(x) = ax^2 + bx + c$, where $a \neq 0$. Its graph is a parabola. The sign of a determines whether it opens upward or downward.

Form	What is easy to read
$ax^2 + bx + c$	The output at input zero is c.
$a(x - r)(x - s)$	When real factors exist, r and s are zeros.
$a(x - h)^2 + k$	The vertex is (h, k); k is a minimum if a is positive and a maximum if a is negative.

EXAMPLE 5.W1 | Read three equivalent forms

Consider $f(x) = x^2 - 6x + 5 = (x - 1)(x - 5) = (x - 3)^2 - 4$. Identify the initial output, zeros and minimum.

Solution

Standard form gives $f(0) = 5$. Factored form gives zeros at inputs 1 and 5.

Vertex form gives the point $(3, -4)$. Since the squared coefficient is positive, the minimum output is -4, at input 3.

In this course, “standard form” means the expanded expression and “vertex form” means the shifted-square expression. The function stays the same when its expression is rewritten correctly.

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LESSON 5

5

Rewrite to expose the feature you need

EXAMPLE 5.W2 | Complete the square

Write $g(x) = x^2 - 8x + 12$ in vertex form and explain the minimum.

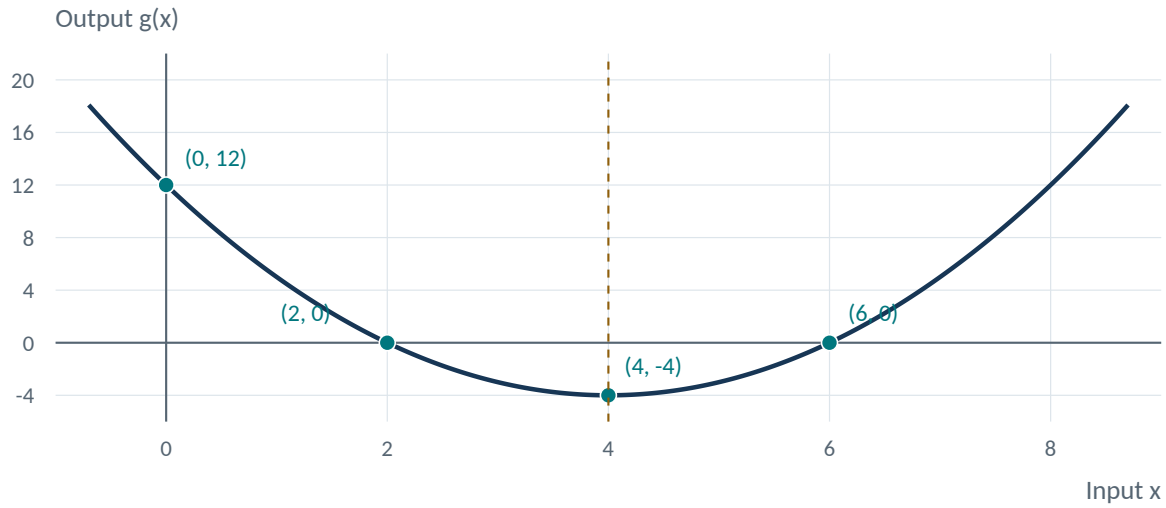
Solution

Half the linear coefficient is -4, and its square is 16. Add and subtract 16 so the value does not change.

$$g(x) = x^2 - 8x + 16 - 16 + 12 = (x - 4)^2 - 4$$

The square is nonnegative. Its smallest value is zero, attained at input 4, so the minimum output is -4.

Factoring the same function gives $g(x) = (x - 2)(x - 6)$. Its zeros are symmetric about $x = 4$. This connects the factored and vertex forms.



The zeros, vertex and initial output describe the same parabola. The axis lies halfway between the two distinct zeros.

CHECK 5.C1

Write $x^2 - 10x + 21$ in vertex form and give its minimum.

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LESSON 5

5

Use structure, not just a memorized step

EXAMPLE 5.W3 | Keep a leading coefficient

Rewrite $p(x) = 2x^2 - 12x + 10$ to reveal its minimum.

Solution

First factor 2 from the quadratic and linear terms: $p(x) = 2(x^2 - 6x) + 10$.

Inside the parentheses, $x^2 - 6x = (x - 3)^2 - 9$.

$$p(x) = 2\big((x - 3)^2 - 9\big) + 10 = 2(x - 3)^2 - 8$$

The minimum is -8 at input 3. The 2 multiplies the entire parenthesized expression, including the subtracted 9.

For equally spaced inputs, a quadratic has constant second differences. Its first differences change linearly. This gives evidence for a quadratic model, but finite data alone do not prove the model at unlisted inputs.

CHECK 5.C2

At inputs $0, 1, 2, 3, 4$, a stated quadratic model has outputs $1, 7, 9, 7, 1$. Identify its maximum and explain using symmetry and differences.

Choose before you calculate

Use standard form for the initial output, factored form for real zeros and vertex form for a maximum or minimum. A request for the least value is a function question, even when it never says “vertex.”

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LESSON 6

Find the greatest or least value

A maximum is an output

In this lesson

Recognize when a question asks for an extreme value, distinguish that output from its input, and check that the chosen input is allowed.

Questions about greatest height, highest revenue, largest area or least cost ask for an output. The input tells you when, where or at what setting that output occurs. A vertex contains both pieces of information.

EXAMPLE 6.W1 | Find height and time

A ball has height $h(t) = -2t^2 + 12t + 5$ meters on $0 \le t \le 6$ seconds. Find its greatest height during this interval and when it occurs.

Solution

The coefficient of the squared term is negative, so the parabola opens downward. Rewrite to expose the maximum.

$$h(t) = -2(t^2 - 6t) + 5 = -2(t - 3)^2 + 23$$

The squared expression is smallest at time 3. That time is allowed, so the greatest height is 23 meters at 3 seconds.

The endpoints both give 5 meters. They are lower than the vertex output, as expected.

Quantity	Answer
Input where the greatest height occurs	3 seconds
Greatest height	23 meters
Vertex as an ordered pair	$(3, 23)$ with time first and height second

CHECK 6.C1

For $R(p) = -4(p - 10)^2 + 900$ on $5 \le p \le 15$, find the maximum revenue and the price that produces it. Revenue and price are both measured in dollars.

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LESSON 6

6

A contextual domain can change the answer

EXAMPLE 6.W2 | The vertex is outside the allowed interval

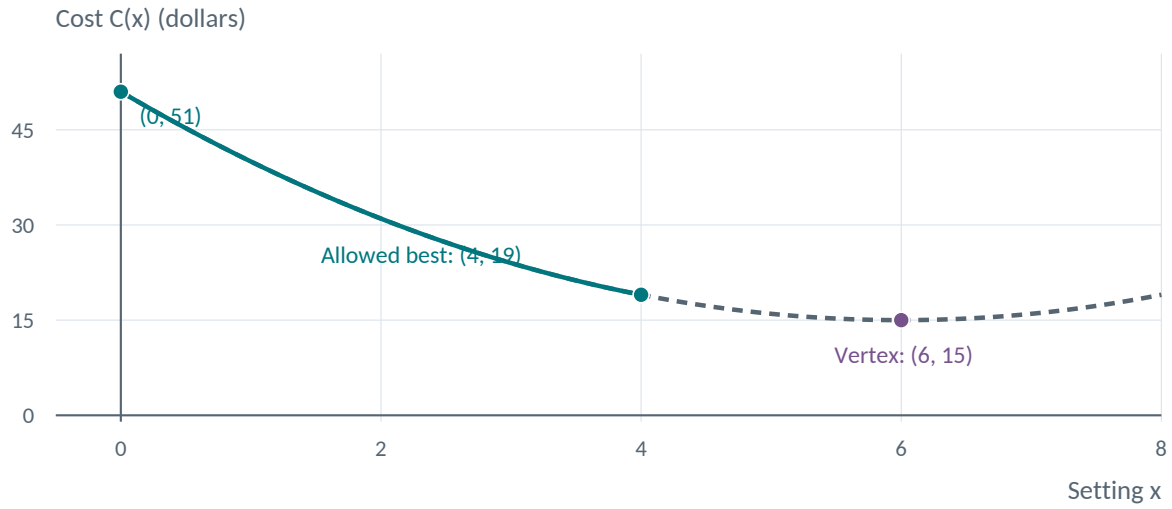
A cost model is $C(x) = (x - 6)^2 + 15$ dollars, but only $0 \le x \le 4$ is allowed. Find the least allowed cost.

Solution

The unrestricted vertex is at input 6, outside the domain. The unrestricted minimum of 15 dollars is therefore not reachable.

On the allowed interval, increasing the setting toward 6 decreases its squared distance from 6. The best allowed setting is 4.

$C(4) = (4 - 6)^2 + 15 = 19$ dollars. At the other endpoint, $C(0) = 51$ dollars.



The teal part is the allowed domain. The unrestricted vertex is shown for comparison, but it is not an allowed setting.

CHECK 6.C2

A model is $F(x) = -(x - 2)^2 + 16$ on $4 \le x \le 7$. Find the greatest allowed output and its input.

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LESSON 6

6

Build the quantity the question asks for

EXAMPLE 6.W3 | Maximize area with a fixed boundary

A rectangle uses 48 meters of fencing on all four sides. Let x be its width. Find the dimensions that give the greatest area.

Solution

The perimeter equation is $2x + 2\ell = 48$, so the length is $\ell = 24 - x$. Positive dimensions require $0 < x < 24$.

The area is $A(x) = x(24 - x) = -x^2 + 24x$.

$$A(x) = -(x - 12)^2 + 144$$

The maximum area is 144 square meters at width 12 meters. The length is also 12 meters. The vertex is in the contextual domain.

For a continuous quadratic on a closed interval, compare the endpoint outputs and the vertex output if its input lies in the interval. The largest candidate is the interval maximum; the smallest is the interval minimum. On an open interval, an excluded boundary value may be approached without being attained.

A four-question check

What quantity is being optimized? Which function represents it? Is the candidate input allowed? Have you reported both the requested output and the input, with their units?

A graph, a table and a rewritten formula can support the same conclusion. Choose a representation that makes the reason for the answer clear.

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7

LESSON
7

Build a quadratic model

When you build a quadratic, first list what you know about its graph. A turning point fixes the center of symmetry. Two zeros fix the horizontal intercepts. Either choice leaves a vertical scale factor to determine. A third point away from the vertex or the zeros usually determines that factor.

EXAMPLE 7.W1

A jump reaches its maximum height of 12 feet at 2 seconds and starts at 4 feet. Build a quadratic height model.

Solution

Write $h(t) = a(t-2)^2 + 12$. At zero, $4 = 4a + 12$, so $a = -2$. Thus $h(t) = -2(t-2)^2 + 12$. Its downward opening and initial height agree with the observations.

Use the point that fixes the scale

$$\begin{aligned} h(t) &= a(t-2)^2 + 12 \\ 4 &= 4a + 12 \\ h(t) &= 12 - 2(t-2)^2 \end{aligned}$$

Substitute the vertex and the starting point into the final equation. Both observations must agree.

The next decision

Three outputs at three distinct inputs also determine at most one quadratic of degree at most two. Substitute the pairs into standard form. Solve the resulting equations, then check the original data. A solution with zero quadratic coefficient gives a line.

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LESSON 7 | WORKED EXAMPLES

7

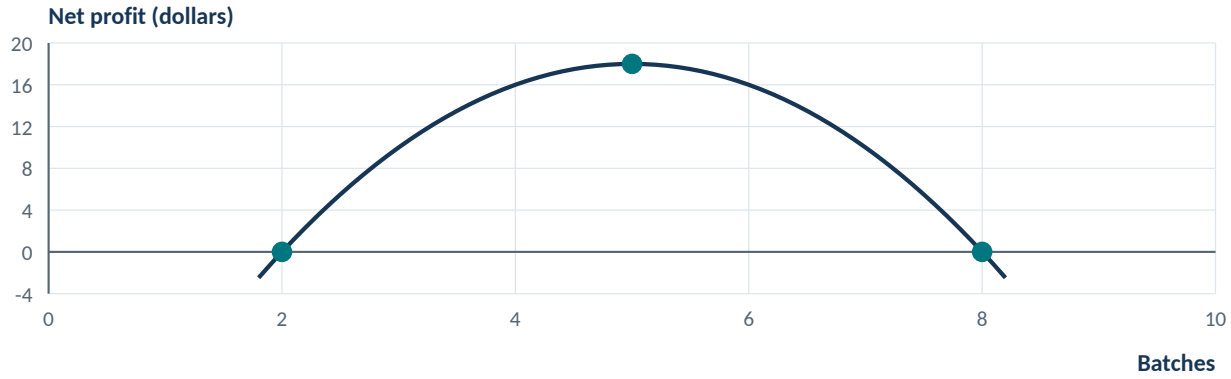
Choose the form that uses your data

EXAMPLE 7.W2

A quadratic profit model breaks even at 2 and 8 batches and earns 18 dollars at 5 batches. Find the model and best output.

Solution

Use $P(n) = a(n-2)(n-8)$. At 5 batches the product is -9, so $a = -2$. The symmetry line is halfway between the zeros at 5, where the profit is 18 dollars.



Profit model for Example 7.W2. The break-even inputs lie on opposite sides of the profitable center.

EXAMPLE 7.W3

A quadratic takes values 3, 6 and 13 at inputs 0, 1 and 2. Recover its coefficients.

Solution

Write $q(x) = ax^2 + bx + c$. Substitution gives $q(0) = c = 3$, $q(1) = a + b + c = 6$ and $q(2) = 4a + 2b + c = 13$. Use $c = 3$ to obtain $a + b = 3$ and $4a + 2b = 10$. Double the first equation to get $2a + 2b = 6$, then subtract it from the second: $2a = 4$. Thus $a = 2$ and $b = 3 - 2 = 1$, so $q(x) = 2x^2 + x + 3$. Checking inputs 0, 1 and 2 gives 3, 6 and 13.

CHECK 7.C

A parabola has vertex $(3, 5)$ and passes through $(5, 13)$. What is its scale factor?

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8

LESSON
8

Exponential patterns and models

Exponential change repeats a multiplication over equal input intervals. If one hour multiplies an amount by b, then two hours multiply it by b^2. A percent increase of 6 uses 1.06. A percent decrease of 6 uses 0.94. State the interval whenever you describe a multiplier.

EXAMPLE 8.W1

A colony starts at 200 and grows 8 percent per day. Predict after two days.

Solution

Each day keeps the current amount and adds 8 percent of it. Use $N(t) = 200(1.08)^t$. Then $N(2) = 233.28$, about 233 organisms under the model.

Change the time interval

$$M_{n \text{ units}} = b^n, \qquad b = \sqrt[n]{M_{n \text{ units}}}$$

A multiplier over four hours belongs to a four-hour interval. Write the time interval before choosing an exponent.

The next decision

If an interval of length n has multiplier M, then the positive one-unit multiplier satisfies $b^n = M$. The forms $AM^{t/n}$ and Ab^t describe the same process when the time origin is zero. With a measured starting point, use elapsed time since that measurement.

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LESSON 8 | WORKED EXAMPLES

8

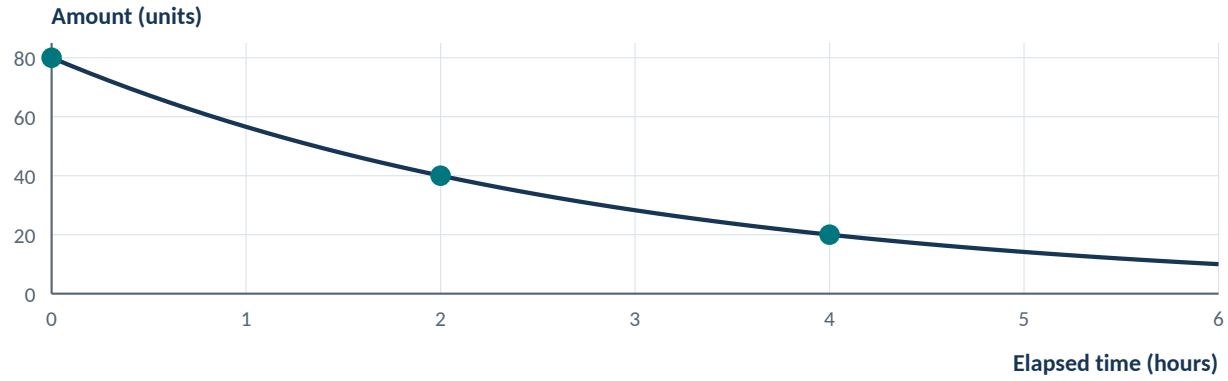
Recover a one-unit multiplier

EXAMPLE 8.W2

A classroom dye sample falls from 80 units to 20 units in 4 hours. Assume exponential decay with a constant percent change per hour. Find a two-hour and a one-hour multiplier.

Solution

The four-hour multiplier is $1/4$. Taking square roots gives a two-hour multiplier of $1/2$ and a one-hour multiplier of $1/\sqrt{2}$. Thus $D(t) = 80(1/2)^{t/2}$.



Dye amounts in Example 8.W2. Each two-hour interval halves the amount.

EXAMPLE 8.W3

At day 2 a count is 18 and at day 5 it is 144. Assume a constant percent change. Find the count at day 4.

Solution

Across three days the multiplier is $144/18 = 8$. In one day it is 2. Anchor at day 2 with $N(t) = 18 \cdot 2^{t-2}$. Day 4 gives 72.

CHECK 8.C

An amount falls 19 percent over two hours. What is the hourly percent change under an exponential model?

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9

DAY
9

Modeling checkpoint

Lessons 1–8

Mixed model choices start with the meaning and spacing of the inputs. Compare changes and ratios, look for symmetry or one turn, and use the context to decide whether a pattern can reasonably continue. Cite a numerical feature before naming a family.

EXAMPLE 9.W1

Outputs at equally spaced inputs 0 through 3 are 15, 12, 9, 6. How could you defend a choice and test it?

Solution

Each increase of one input unit subtracts 3. A linear candidate is $15 - 3x$. At 4 it predicts 3. A new observation there can test whether the decrease continues.

After the individual checkpoint, compare two explanations that use different representations. A correct calculation earns its meaning only after you identify the requested quantity, its units and the allowed inputs.

EXAMPLE 9.W2

A ball's height in meters is $h(t) = 10 + 4t - t^2$ on $[0, 4]$. Which reading should a photographer anticipate at the top of the flight?

Solution

Rewrite as $14 - (t - 2)^2$. The square is smallest at 2 seconds, producing the largest height, 14 meters. Report both the output and its time.

CHECK 9.C

An interval rate is zero. Give an example with a changing output.

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LESSON
10

Fit models with technology

A regression fits a family of curves to observed pairs. Put input in the first column and output in the second. Plot the points before fitting. Use a straight line for roughly constant rates, a quadratic for a changing rate with a plausible turn, or a positive exponential for roughly constant relative change.

EXAMPLE 10.W1

For inputs 0, 1, 2, 3 the outputs are 3, 4, 7, 8. Fit a line and predict at 2.5.

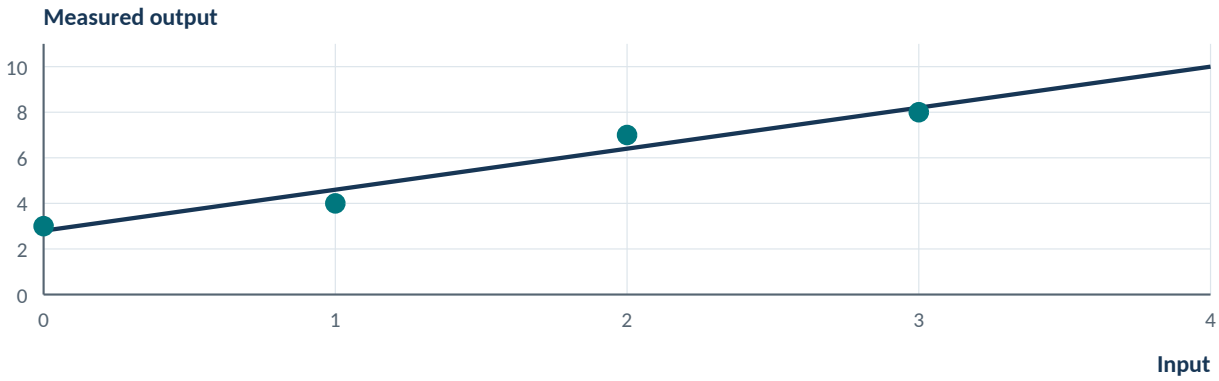
Solution

Linear regression gives $L(x) = 1.8x + 2.8$. It predicts $L(2.5) = 7.3$. The rate is 1.8 output units per input unit. The prediction lies within the observed input range.

Read a fitted coefficient

$$L(2.5) = 1.8(2.5) + 2.8 = 7.3$$

The input 2.5 is halfway between measured inputs 2 and 3. The fitted line interpolates between its own predictions at those inputs.



Data and fitted line for Example 10.W1. The measured points lie on both sides of the line.

The next decision

On a graphing calculator, enter the data in two lists or columns. Choose linear, quadratic or exponential regression and save the fitted equation. In Desmos use a table and enter $y_1 \sim mx_1 + b$, $y_1 \sim ax_1^2 + bx_1 + c$, or $y_1 \sim ab^{x_1}$. Keep full coefficients for predictions. Report units and sensible precision. For Example 10.W1, enter the four input-output pairs in a table, then fit the line. The tool reports $m = 1.8$ and $b = 2.8$. Define $L(x) = mx + b$ with the fitted values and evaluate $L(2.5)$. Check that the plotted line lies near the observations. A regression command finds coefficients; the context determines whether the family and prediction are reasonable.

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LESSON 10 | WORKED EXAMPLES

10

Compare fits and predictions

EXAMPLE 10.W2

Heights at seconds 0, 1, 2, 3, 4 are 1, 4, 5, 4, 1 meters. Fit a quadratic and interpret the turn.

Solution

Quadratic regression gives $h(t) = -t^2 + 4t + 1 = 5 - (t - 2)^2$. The model reaches 5 meters at 2 seconds. Restrict the interpretation to the measured flight.

EXAMPLE 10.W3

Amounts at hours 0, 2 and 4 are 10, 22.5 and 50.625. Fit an exponential and predict at hour 3.

Solution

The two-hour multiplier is 2.25, so software returns $Q(t) = 10(1.5)^t$. At hour 3 this is 33.75. Hour 12 would require the growth to persist well beyond the evidence.

CHECK 10.C

A degree-two regression fits three measurements exactly. What independent evidence would strengthen its use as a model?

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LESSON
11

Construct and interpret residuals

At each observed input, compare the measured output with the height of the fitted curve directly above or below it. The signed vertical difference is the residual $r = y - \hat{y}$. A positive residual places the observation above the model. A negative residual places it below.

EXAMPLE 11.W1

The estimated load of a bin is 18 kg. The measured load is 16.5 kg. Locate the residual relative to zero.

Solution

Subtract in the order observed minus predicted. The residual is $16.5 - 18 = -1.5$ kg. The bin is 1.5 kg lighter than predicted, so plot the point below zero.

Retain the direction of the error

$$r_i = y_i - \hat{y}_i, \qquad \text{SSE} = \sum_{i=1}^{n} r_i^2$$

Use the original input when plotting a residual. The residual has the output units, while the squared sum has squared output units.

The next decision

A residual plot places each original input on the horizontal axis and its residual on the vertical axis. The horizontal zero line represents a perfect prediction. To compare two candidates for the same data and output units, sum the squared residuals. Squaring prevents opposite signs from cancelling and gives more weight to large misses. A least-squares regression searches within a chosen function family for coefficients that make this sum as small as possible. A smaller sum than one competing model establishes which of those two fits better; it does not prove that either is the best fit in the entire family.

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LESSON 11 | WORKED EXAMPLES

11

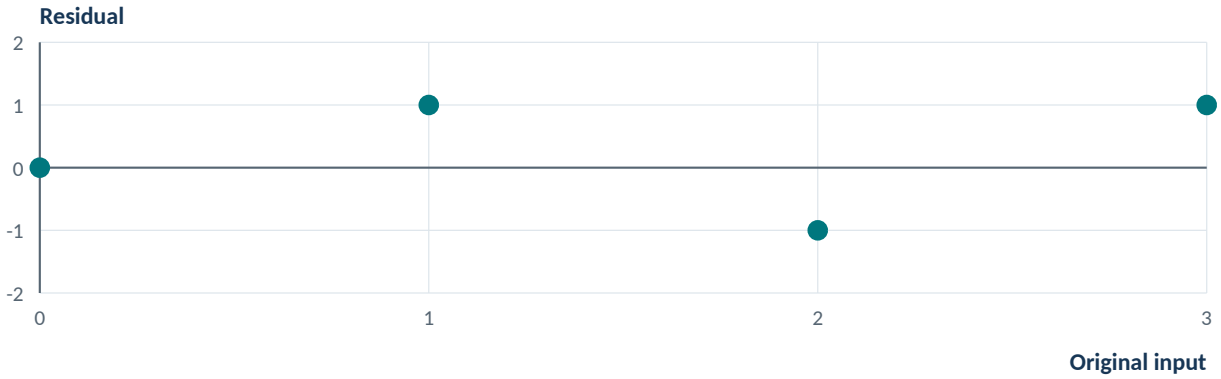
Read the residual plot and compare errors

EXAMPLE 11.W2

For inputs 0, 1, 2, 3 the measurements are 2, 5, 5, 9. Use $L(x) = 2x + 2$. Build a residual plot.

Solution

Predictions are 2, 4, 6, 8. Subtract to get 0, 1, -1, 1. Plot $(0, 0)$, $(1, 1)$, $(2, -1)$, $(3, 1)$. The plotted heights have the units of the measured output.



Residuals for Example 11.W2, plotted at the original inputs.

EXAMPLE 11.W3

Compare the preceding line with $M(x) = 2x + 3$ on the same four points.

Solution

The first sum of squared residuals is $0 + 1 + 1 + 1 = 3$. The second line predicts 3, 5, 7, 9, giving residuals $-1, 0, -2, 0$ and sum 5. Among these two candidates, the first fits better by this criterion.

CHECK 11.C

A residual at input 6 is -4 and the predicted output is 19. Recover the observation.

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LESSON
12

Use residual patterns to question a model

Read a residual plot from left to right. A long run above zero means the model repeatedly predicts too little over those inputs. A bowed pattern may indicate curvature missing from a line. A fan shape suggests changing error size, even when residuals are centered near zero.

EXAMPLE 12.W1

For increasing inputs, residuals from a line are $4, 0, -3, 0, 4$. Describe the problem.

Solution

The line predicts too little at both ends and too much at the middle. A U-shaped pattern suggests trying an upward-curving family, then checking its residuals on the same inputs.

Read the sign at a point

$$r > 0 \implies y > \hat{y}, \qquad r < 0 \implies y < \hat{y}$$

Follow adjacent inputs. Several misses in the same direction may reveal a systematic problem even when each individual error is small.

The next decision

Use both the size and the arrangement of the errors. Two models can have equal squared errors yet miss in different ways. Ask which part of the input domain was observed, which mechanisms could change there, and which future observation could challenge your explanation.

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LESSON 12 | WORKED EXAMPLES

12

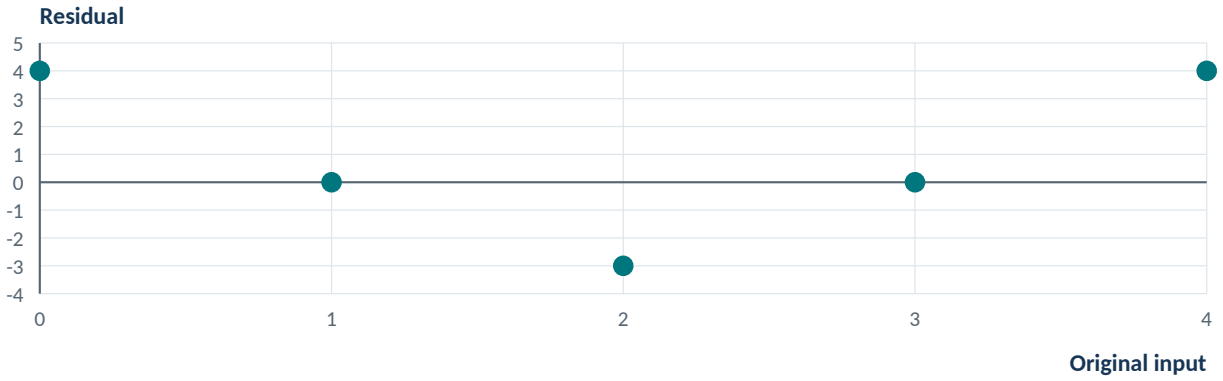
Check pattern, size and domain

EXAMPLE 12.W2

A second set of line residuals is $1, -2, 1, 0, -1$. What conclusion is warranted?

Solution

Signs vary around zero without an obvious curve in these five observations. The line is a reasonable candidate over this range. A new observation gives a stronger test than inspecting these same five again.



Residuals for Example 12.W1. Positive errors at the ends and negative errors at the center form a curved pattern.

EXAMPLE 12.W3

A speed model is defined algebraically at every time. Measurements cover minutes 2 through 6. The machine is switched off at minute 9. Compare predictions at 5 and 12.

Solution

Minute 5 is inside the measured interval. Minute 12 is outside it and follows a change in how the machine operates. A single formula may produce a number at 12 while its assumptions have already failed.

CHECK 12.C

Residuals grow from roughly half a unit to about five units in magnitude as inputs increase, with both signs present. What changes in the predictions?

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DAY
13

Table Rocks modeling investigation

Lessons 8 and 10–12

A modeling investigation begins with a question a measurement can answer. The seasonal pools on the Table Rocks give us a setting for a model of changing water depth. The readings in today's exercise are simulated. Use the data supplied in class and keep the units attached to the predictions.

EXAMPLE 13.W1

For a separate simulated series, water depth on days 0, 1, 2 is 20, 16, 12.8 cm. Compare equal-step changes and ratios.

Solution

Differences are $-4, -3.2$. Ratios are 0.8 and 0.8. One candidate is $D(t) = 20(0.8)^t$ cm. This predicts 10.24 cm at day 3 if the pattern continues.

A short report should show a labeled plot, a candidate equation, residual evidence and one prediction whose use you can defend. State the time span and how rain, evaporation or a change in conditions might affect your conclusion. Focus on evidence a person could actually collect.

EXAMPLE 13.W2

A candidate predicts 6.4 cm at day 5. A fresh reading gives 7.1 cm. What should the report say?

Solution

The residual is $7.1 - 6.4 = 0.7$ cm. The model underpredicted. Record the new point and compare with earlier residuals. One miss does not identify a cause such as rain.

CHECK 13.C

Design a measurement that can assess prediction rather than just reproduce a fit.

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14

LESSON
14 Read and evaluate piecewise rules

A piecewise rule chooses a formula by input. Read the interval first, then evaluate only its assigned expression. At a boundary, an inequality with equality or a filled graph point includes the input. An open point indicates the limiting height of an excluded endpoint.

EXAMPLE 14.W1

A charge is 4 dollars for $0 \le t \le 2$ hours and $4 + 3(t - 2)$ dollars for $2 < t \le 6$. Evaluate at 2 and 2.5 hours.

Solution

The first branch owns 2, so the charge is 4 dollars. The second branch gives $4 + 3(0.5) = 5.50$ dollars at 2.5 hours.

Write the boundary into the rule

$$C(t) = \begin{cases} 4, & 0 \le t \le 2, \\ 4 + 3(t - 2), & 2 < t \le 6. \end{cases}$$

At the changeover, equality belongs to exactly one branch. The value can match the limiting height of the other branch.

The next decision

A vertical line through the input meets the graph at the output if a filled point or included segment exists there. At a jump, the height approached from one side can differ from the actual value. Record units and label any estimate read between coordinate marks.

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LESSON 14 | WORKED EXAMPLES

14

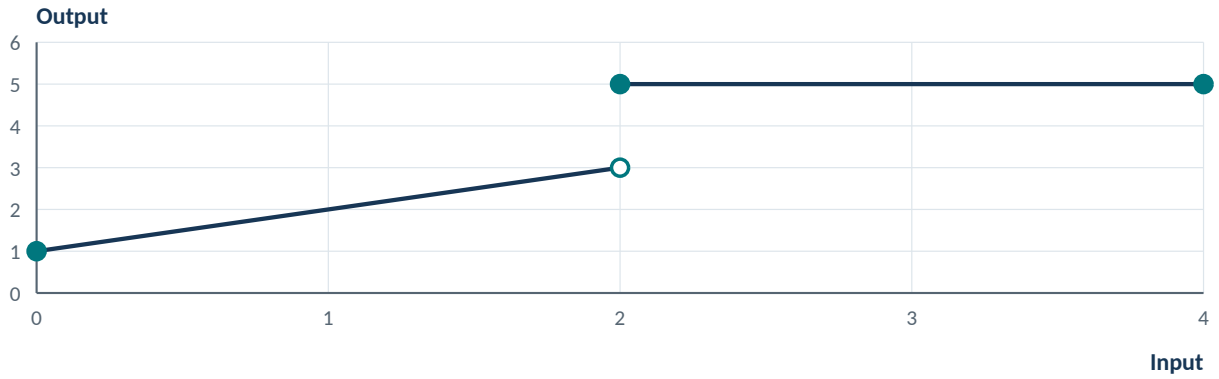
Read a boundary from its graph

EXAMPLE 14.W2

Read the accompanying graph at input 2, just below 2, and at 3.

Solution

The filled point at input 2 has height 5. The lower branch approaches 3 as the input approaches 2 from the left. On the upper segment at 3 the graph gives 5.



Graph for Example 14.W2. A filled marker includes the endpoint; an open marker excludes it.

EXAMPLE 14.W3

A rule uses $x + 2$ on $[-1, 1)$ and $4 - x$ on $[1, 3]$. State its domain and determine whether it jumps at 1.

Solution

The intervals together give $[-1, 3]$. The left-hand height approaches 3 and the right branch takes the value 3 at 1. Both pieces meet there.

CHECK 14.C

A filled dot is at $(4, 7)$ and an open dot at $(4, 2)$. State the output at 4 and explain which mark supplies it.

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LESSON
15 Construct piecewise models

Start a piecewise model by marking each input at which the situation changes. Decide who owns each boundary. For a cumulative charge, first calculate the total already earned or paid at that boundary. Add the new rate times the amount above the threshold.

EXAMPLE 15.W1

A hypothetical bike rental near the Bear Creek Greenway charges 6 dollars for the first hour and 2 dollars per additional hour, prorated continuously, up to five hours. Model the cost for positive rental times.

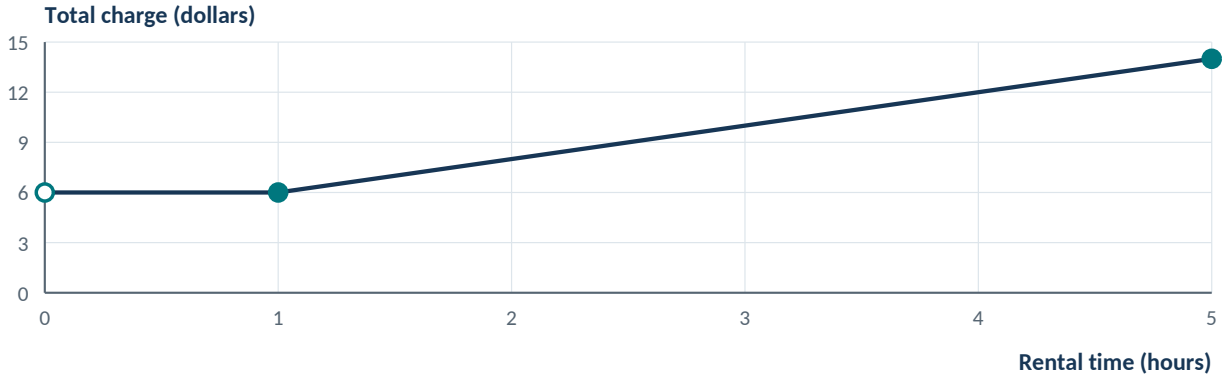
Solution

Use 6 on $(0, 1]$ and $6 + 2(t - 1)$ on $(1, 5]$. At 2.5 hours the cost is 9 dollars. The horizontal segment meets the rising segment at $(1, 6)$.

Carry the accumulated amount forward

$$C(t) = \begin{cases} 6, & 0 < t \le 1, \\ 6 + 2(t - 1), & 1 < t \le 5. \end{cases}$$

One and a half hours includes the first hour and one half-hour at the additional rate, so the total is 7 dollars.



The classroom rental model in Example 15.W1. The rate changes after one hour.

The next decision

Graph each formula only on its interval. A new marginal rate changes the slope. A flat fee for crossing a threshold can create a jump. Which shape is plausible depends on what the price rule charges for the first units after the boundary.

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LESSON 15 | WORKED EXAMPLES

Choose intervals and carry a total forward

EXAMPLE 15.W2

A club pays 12 dollars for up to 10 prints and a flat 18 dollars for 11 through 20 prints. Build and sketch a model.

Solution

Use integer counts 1 through 20. Plot discrete points of height 12 at 1 through 10 and height 18 at 11 through 20. The input counts exclude fractional prints.

EXAMPLE 15.W3

A cyclist rides away at 12 km/h for 0.5 hour, then at 8 km/h for 0.75 hour. Give the second rule in elapsed time from the original start.

Solution

At the change the distance is 6 km. For $0.5 < t \leq 1.25$, use $d(t) = 6 + 8(t - 0.5)$. The final distance is 12 km. Starting the second branch at zero distance would discard the first half-hour.

CHECK 15.C

A tank holds 30 liters at minute 4 and then drains 3 liters a minute. Write the rule on $[4, 14]$.

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16

LESSON
16

Absolute value as distance and a piecewise rule

The absolute value of a number is its distance from zero. For a point x on a number line, $|x - h|$ measures distance from the reference point h. Inputs on opposite sides of h can produce the same distance. The graph turns where the inside expression changes sign.

EXAMPLE 16.W1

A target mass is 12 kg. Define deviation without a sign and find both masses 1.5 kg from target.

Solution

$D(m) = |m - 12|$. The locations are $12 - 1.5 = 10.5$ and $12 + 1.5 = 13.5$ kg. The absolute value records the size of the miss.

Express distance in two pieces

$$|x - h| = \begin{cases} h - x, & x < h, \\ x - h, & x \geq h. \end{cases}$$

Try an input two units to each side of h. On either branch the distance comes out positive and equal to two.

The next decision

For $x < h$, the distance is $h - x$. For $x \geq h$, it is $x - h$. Scale these branches and add a baseline to model a penalty, tolerance or amount that changes with distance from a target. Sketch the meeting point before extending the branches.

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LESSON 16 | WORKED EXAMPLES

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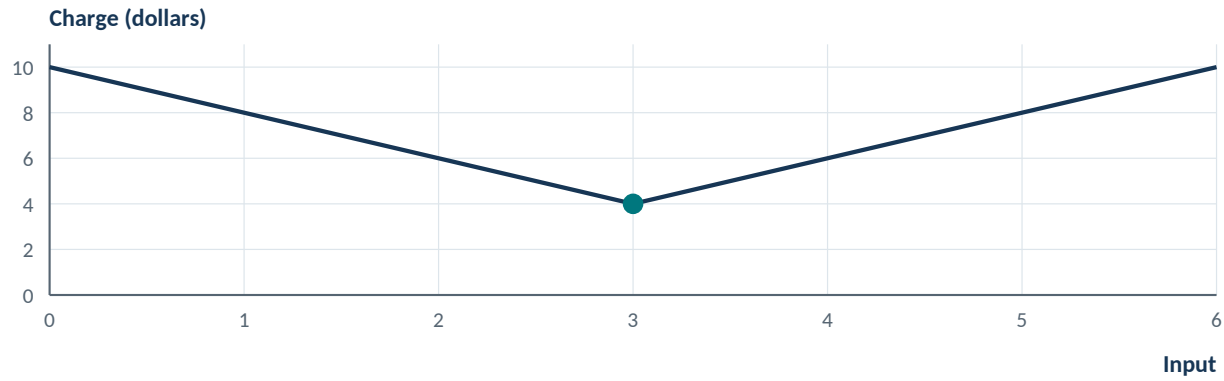
Find both branches of a distance rule

EXAMPLE 16.W2

Write $C(x) = 2|x - 3| + 4$ in branches and graph it.

Solution

For $x < 3$ use $2(3 - x) + 4 = 10 - 2x$. For $x \geq 3$ use $2(x - 3) + 4 = 2x - 2$. The rays meet at $(3, 4)$, with slopes -2 and 2.



Graph of the charge in Example 16.W2. The lowest charge occurs at input 3. This is a viewing window; both branches continue.

EXAMPLE 16.W3

A scoring rule $S(t) = 20 - 3|t - 5|$ uses $1 \leq t \leq 9$. Find the highest score and both inputs yielding 14.

Solution

The penalty vanishes at 5, giving 20. A score of 14 requires $|t - 5| = 2$, so $t = 3$ or 7. Both are in the scoring window.

CHECK 16.C

For $x < 4$, explain why $|x - 4| = 4 - x$.

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17

DAY
17

Modeling with Functions review

Lessons 1–16

Choose a representation by the question. A turning point can answer a greatest-value question, a secant slope compares net changes, a residual measures a prediction error and a change in rule calls for intervals. Write the quantity and units before deciding which calculation to perform.

EXAMPLE 17.W1

A film clip models height $h(t) = 12 + 8t - 2t^2$ for $0 \le t \le 5$. What height must the camera frame include?

Solution

Rewrite as $20 - 2(t - 2)^2$. The highest point lies in the clip at time 2, reaching 20 height units. The model's output, rather than its time, determines the frame height.

Use the short diagnostic to select a group. Work through the route your teacher assigns, then return to a mixed independent task. A correct answer after a hint and a correct answer on a fresh problem give different information about readiness.

EXAMPLE 17.W2

Two models agree at time 0 and time 6. Can a reading at time 3 help select one?

Solution

Yes if their predictions at 3 differ. Calculate each prediction before collecting the observation, then compare signed and absolute errors. A matching endpoint cannot distinguish models known to agree there.

CHECK 17.C

Which details in a distance-charge story justify using different rules?

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DAY
18

Modeling with Functions exam

Lessons 1–16 ● Review on Day 17

For today's unit assessment, show why your chosen method fits the quantities. On a model-building task, define the input and output. On a graph, label the scale and any relevant endpoints. Check the domain before reporting a prediction or an extreme.

EXAMPLE 18.W1

A quadratic model has a maximum of 40 at input 5, but its permitted continuous input domain is $[0, 3]$. How would you find its greatest permitted output, and what additional information is needed for a numerical value?

Solution

For a downward-opening parabola the valid point closest to 5 is 3, so evaluate the rule at 3. The stated maximum alone gives no numerical height there without the scale factor.

After the exam, revisit one question from memory. State the decision you had to make and work the parallel task in your workbook. Your teacher can compare the two attempts once the exam is scored.

EXAMPLE 18.W2

A model predicted 8, 10, 12 while the observations were 9, 8, 14. What does a residual table tell us?

Solution

Residuals are $1, -2, 2$. The middle observation is below its prediction. Their squared sum is 9. With three readings, any broad claim about a pattern needs more evidence.

CHECK 18.C

What can you do after writing an equation to check that it represents the situation?

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19

LESSON
19

Composition as an input-output chain

A composition feeds one function's output into a second function. Read $g(f(x))$ from the inside out. First calculate f on the original input. Then use that result as the input to g. The units leaving the inner rule must make sense as units entering the outer rule. The notation $(g \circ f)(x) = g(f(x))$ names the same composite: apply f first, then g. The circle means composition, not multiplication.

EXAMPLE 19.W1

A club orders $b(n) = 2n + 1$ boxes for n teams. Each box costs 6 dollars. Find the cost for four teams.

Solution

The sequence is teams, boxes, dollars. $C(b(4)) = 6(2 \cdot 4 + 1) = 54$ dollars. Nine boxes are the intermediate quantity.

Follow one input

$$4 \text{ teams} \longmapsto 9 \text{ boxes} \longmapsto 54 \text{ dollars}$$

The intermediate value names a count of boxes. That is precisely the input the next calculation expects.

The next decision

A composite is defined only when the original input belongs to the inner domain and its output belongs to the outer domain. To construct its formula, substitute the entire inner expression into every occurrence of the outer variable. Parentheses keep the substitution intact.

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LESSON 19 | WORKED EXAMPLES

Compare orders and restrict the domain

EXAMPLE 19.W2

Let $f(x) = x + 3$ and $g(u) = u^2 - u$. Find both compositions and compare at input 2.

Solution

$g(f(x)) = (x + 3)^2 - (x + 3)$ gives 20 at 2. $f(g(x)) = x^2 - x + 3$ gives 5 at 2. The two orders use different intermediate quantities.

EXAMPLE 19.W3

Use $f(x) = 2x - 4$ and $g(u) = \sqrt{u}$. Find the domain of each order.

Solution

$g(f(x)) = \sqrt{2x - 4}$ requires $x \geq 2$. For $f(g(x)) = 2\sqrt{x} - 4$, the square root is applied first and requires $x \geq 0$.

CHECK 19.C

A job takes $h(n) = 3n$ hours and pays $p(h) = 18h + 10$ dollars. Interpret $p(h(2))$.

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20

LESSON
20 Compose tables and graphs

A table, graph and formula can each supply one stage of a chain. Start a row with the original input and add one column for each intermediate output. A blank entry can mean the available information is incomplete. An input outside a stated domain makes that stage undefined.

EXAMPLE 20.W1

The complete table for f on inputs 0, 1, 2 gives 2, 4, 1. A complete table for g on 1, 2, 3 gives 5, 7, 9. Construct $g \circ f$.

Solution

Input 0 goes to 2 and then 7. Input 1 goes to 4, outside the domain of g. Input 2 goes to 1 and then 5. Plot just $(0, 7)$ and $(2, 5)$ for this discrete composite.

Test both domains

$$x \in \text{dom}(f), \qquad f(x) \in \text{dom}(g)$$

Only after both tests pass can you enter the final point on the graph of the composite.

The next decision

To sketch a composite, pair each valid original input with the final output. Additional assumptions determine whether to connect these points. A table for a discrete domain gives isolated points. A continuous graph may support interpolation and approximate readings between marked points.

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LESSON 20 | WORKED EXAMPLES

20

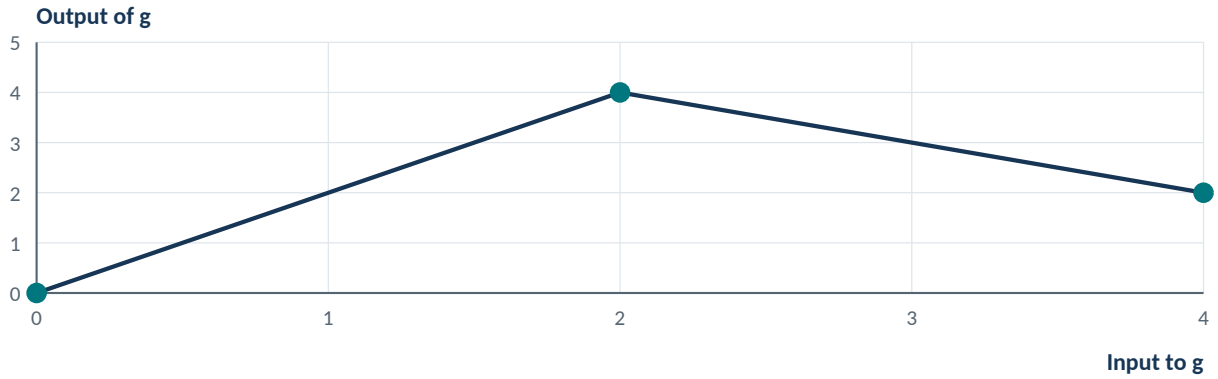
Use a graph inside a longer chain

EXAMPLE 20.W2

Read $g(2)$ from the accompanying graph. If $f(3) = 2$ and $h(v) = 2v + 1$, evaluate $h(g(f(3)))$.

Solution

Use 3 as the original input: f gives 2, the graph of g gives 4, and h gives $2(4) + 1 = 9$. The final pair for the chain is $(3, 9)$.



Outer function g for Example 20.W2. Read the graph after evaluating the inner function.

EXAMPLE 20.W3

A graph of f gives outputs about 1.5 and 2.5 at inputs 0 and 1. Let $g(u) = 4 - u$. Predict the first two points of the composite graph.

Solution

Pair 0 with $4 - 1.5 = 2.5$ and 1 with $4 - 2.5 = 1.5$. A small reading error in f carries through the outer rule, so these plotted points are approximate.

CHECK 20.C

A table lists only some values of a real function. The entry at 5 is missing. What can you say about a chain needing that entry?

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21

LESSON
21 Decompose a function

Decomposition asks which simpler rules could have produced a given function. Look for an expression used as a unit, such as the quantity inside a square or a repeated factor. Name it u, then rewrite the full output in terms of u. More than one decomposition can work.

EXAMPLE 21.W1

Decompose $F(x) = (3x - 2)^2 + 5$ into two functions.

Solution

Take $g(x) = 3x - 2$ and $h(u) = u^2 + 5$. Then $h(g(x)) = (3x - 2)^2 + 5$. Alternatively first square $3x - 2$ as part of the inner function and make the outer operation addition of 5.

Verify in the original variable

$$h(g(x)) = (3x - 2)^2 + 5$$

Write the intermediate variable in parentheses where the outer function expects its input. Then compare the resulting rule and domain to the original.

The next decision

The identity $I(x) = x$ gives $F = F \circ I = I \circ F$ on the appropriate domain. To find a more informative decomposition, describe substantive operations in order. Recompose, simplify and check the domain of the resulting chain.

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LESSON 21 | WORKED EXAMPLES

Decompose a product or a three-stage rule

EXAMPLE 21.W2

Find a nontrivial decomposition of $P(x) = (x - 1)(x + 3)$ using its factors.

Solution

Set $u = x - 1$. The second factor is $u + 4$. Use $g(x) = x - 1$ and $h(u) = u(u + 4)$. Recomposing gives $(x - 1)((x - 1) + 4) = (x - 1)(x + 3)$.

EXAMPLE 21.W3

Write $T(x) = 4\sqrt{x + 2} - 1$ as three functions. Give the domain.

Solution

Use $a(x) = x + 2$, $b(u) = \sqrt{u}$ and $c(v) = 4v - 1$. Then $c(b(a(x))) = 4\sqrt{x + 2} - 1$. The middle stage requires $x \geq -2$.

CHECK 21.C

For $F(x) = (x + 5)^3$, give both an identity decomposition and a nontrivial decomposition.

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22

LESSON
22 Translations and reference points

Track one marked point on the original graph. If $f(u) = v$, adding k outside the function gives $v + k$ at the same input u. For $g(x) = f(x - h)$ the old output v occurs where $x - h = u$, which gives $x = u + h$. The reference point moves horizontally by h.

EXAMPLE 22.W1

A point $(2, 7)$ lies on f. Locate the corresponding point on $g(x) = f(x - 3) + 4$.

Solution

Set $x - 3 = 2$ to recover the old input. The new input is 5, and the output becomes 11. The point moves to $(5, 11)$.

Recover the original input

$$x - h = u \quad \Longrightarrow \quad (u, v) \longmapsto (u + h, v + k)$$

This point mapping applies to the graph of the translated rule with inner expression x minus h and outer addition k.

The next decision

With $A_h(x) = x + h$, a vertical translation is $A_k \circ f$. An input translation such as $f(x + h)$ is $f \circ A_h$. The order determines whether the addition changes the original input or the final output. Translate endpoints along with the rest of the graph.

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LESSON 22 | WORKED EXAMPLES

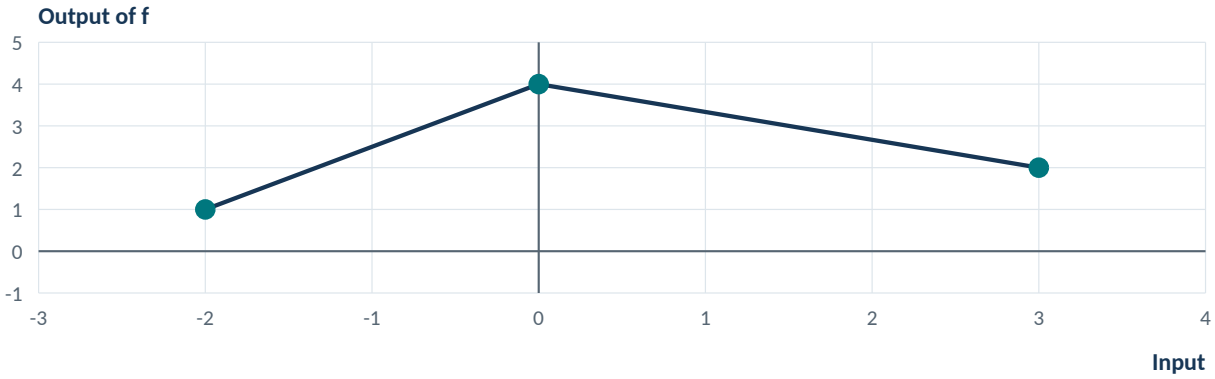
Move a graph and change a clock

EXAMPLE 22.W2

A graph joins $(-2, 1), (0, 4), (3, 2)$. Sketch $f(x + 1) - 2$.

Solution

Solve $x + 1 = u$ so each input decreases by one. Subtract two from each output. Join $(-3, -1), (-1, 2), (2, 0)$ with the original segment shapes. The new domain is $[-3, 2]$.



Original graph in Example 22.W2, before the translation.

EXAMPLE 22.W3

A trip record D measures distance in miles t minutes after 8 a.m. Write distance s minutes after 7:50 a.m. for the same trip.

Solution

At $s = 10$ the old clock reads zero, so $t = s - 10$. Use $D(s - 10)$. This coordinate change places the original start ten minutes to the right on the new clock.

CHECK 22.C

If $f(-1) = 6$, locate the corresponding point of $g(x) = f(x + 5)$.

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23

LESSON
23 Scaling and reflections

For a point (u, v) on f, the graph of $af(x)$ contains (u, av). For $f(bx)$ solve $bx = u$ before placing the point: its coordinates become $(u/b, v)$. The magnitude of a scale factor describes the change in size. Its sign determines whether the corresponding coordinates also reflect across an axis.

EXAMPLE 23.W1

Suppose $f(6) = 4$. Track that point on $2f(x)$ and $f(2x)$.

Solution

Doubling output gives $(6, 8)$. To recover the old input 6 in the second rule, use $2x = 6$, giving $(3, 4)$. The horizontal scale factor is one half.

Keep the two coordinates separate

$$g(x) = af(bx) \quad \Longrightarrow \quad (u, v) \longmapsto \left(\frac{u}{b}, av\right), \quad b \neq 0$$

Check the horizontal move by tracing the new input back through multiplication by b. The resulting inner input must equal u.

The next decision

With $M_c(x) = cx$ and nonzero c, output scaling is $M_c \circ f$. Input scaling is $f \circ M_c$. A negative outer multiplier reflects across the horizontal axis; a negative inner multiplier reflects across the vertical axis. Use an asymmetric graph so different transformations are visible.

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LESSON 23 | WORKED EXAMPLES

Combine reflections and scaling

EXAMPLE 23.W2

A graph has a corner at $(-2, 3)$. Locate it under $-3f(-x/2)$.

Solution

Solve $-x/2 = -2$, so the new input is 4. Multiply the old output by -3, giving -9. New corner $(4, -9)$. The graph widens by 2 and reflects horizontally, then scales vertically by 3 and reflects vertically.

EXAMPLE 23.W3

The domain of f is $[-2, 4]$ and the range is $[1, 5]$. Find both for $g(x) = -2f(3x)$.

Solution

For the input, require $-2 \leq 3x \leq 4$, so the domain is $[-2/3, 4/3]$. Scaling outputs by -2 reverses their order, giving range $[-10, -2]$.

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LESSON 23 | GRAPH COMPARISON

23

Vertical and horizontal dilation

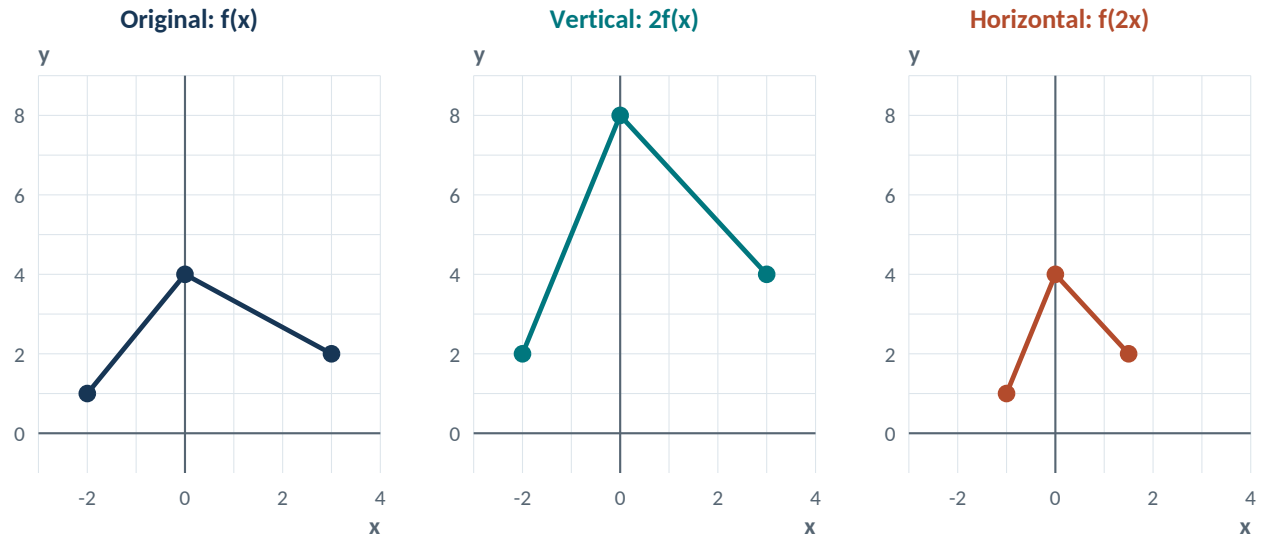
EXAMPLE 23.W4 | Track the coordinates

Let f be the piecewise-linear function joining $(-2, 1)$, $(0, 4)$ and $(3, 2)$, with domain $[-2, 3]$. Sketch $2f(x)$ and $f(2x)$.

Solution

For $2f(x)$, keep the input and double the output. For $f(2x)$, solve $2x = u$ for each old input u: the new input is $u/2$, and the output stays the same.

Original $(u, f(u))$	$2f(x)$: $(u, 2f(u))$	$f(2x)$: $(u/2, f(u))$
$(-2, 1)$	$(-2, 2)$	$(-1, 1)$
$(0, 4)$	$(0, 8)$	$(0, 4)$
$(3, 2)$	$(3, 4)$	$(1.5, 2)$



Join the mapped points with straight segments. The windows use identical scales. The domain of $2f(x)$ is $[-2, 3]$ and its range is $[2, 8]$. The domain of $f(2x)$ is $[-1, 1.5]$ and its range is $[1, 4]$.

CHECK 23.C

If $(8, -3)$ is on f, where does it go under $f(-2x)$?

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LESSON
24

Build transformations in context

When a model changes units or reference points, write the old input in terms of the new input first. Feed that expression into the old rule. Then convert the old output to the requested output units and adjust its reference level. A test point with a known physical meaning often reveals a reversed conversion.

EXAMPLE 24.W1

Upper Table Rock's published round-trip trail distance is 2.5 miles. Let $d(t)$ be distance traveled in miles after t minutes of a hypothetical outing. Write distance in km after h hours and convert the full published distance using 1 mile = 1.609344 km.

Solution

Use $D(h) = 1.609344d(60h)$. At the end, 2.5 miles becomes 4.02336 km. The trail distance comes from BLM. The function and the hiker's timing belong to this classroom example.

Send new units through the old rule

$$h \text{ hours} \longmapsto 60h \text{ minutes} \longmapsto d(60h) \text{ miles} \longmapsto 1.609344d(60h) \text{ km}$$

The recorded quantity is cumulative distance traveled. On a completed out-and-back walk, this distance can be positive even though displacement is zero.

The next decision

Suppose $f(t)$ measures height in feet t minutes after a start. For s seconds after that same start and height in inches, use $12f(s/60)$. The input conversion occurs before evaluation and the output conversion after it. If the clocks have different origins, convert and align the origins before evaluating.

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LESSON 24 | WORKED EXAMPLES

24

Convert a clock and a measurement

EXAMPLE 24.W2

A school logger gives temperature $T(m)$ in degrees Celsius m minutes after 9 a.m. Record Fahrenheit temperature h hours after 8 a.m.

Solution

At 9 a.m. the new clock shows 1. Thus $m = 60(h - 1)$ and $F(h) = 1.8T(60(h - 1)) + 32$. At $h = 1$, the logger must receive input zero.

EXAMPLE 24.W3

The National Park Service lists Crater Lake's greatest depth as 1,943 feet. A classroom depth diagram uses $d(x)$ feet below the surface at distance x miles along an imagined transect. Build a rule for signed elevation in meters relative to the water surface, with input k in km.

Solution

Depth is positive downward; elevation here is positive upward. Convert input by $x = k/1.609344$ and output by $E(k) = -0.3048d(k/1.609344)$. A depth of 1,943 feet corresponds to about -592.23 meters. No measured lake profile is supplied.

CHECK 24.C

An original rule uses minutes after noon. For s seconds after 12:05, what input belongs inside the old rule?

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DAY
25

Mod 1 cumulative check

Lessons 1–24

The mod check combines two kinds of decisions. In a modeling problem, choose the relationship represented by the data. In a function-algebra problem, decide which quantity enters the next rule and what the output means. A sketched point often checks an input conversion more quickly than redoing the algebra.

EXAMPLE 25.W1

A point $(2, 7)$ belongs to a graph. A new display uses $g(x) = 3f(x - 4) - 1$. Find the corresponding point and verify it.

Solution

Use $x - 4 = 2$, so $x = 6$. Output $3(7) - 1 = 20$. Substituting at 6 uses the original value $f(2)$.

Use the work after the check to prepare a short personal re-entry plan. Save one fresh example you can solve from memory, one explanation that helped you, and one skill to revisit when the next mod begins.

EXAMPLE 25.W2

A kiosk sells whole bundles, with profit $P(n) = 30 - (n - 4.5)^2$ for counts 1 through 7. Which feasible counts give the highest profit?

Solution

Counts 4 and 5 are each half a unit from the vertex. Both give 29.75 dollars. Other whole counts have a larger squared distance and a smaller profit.

CHECK 25.C

Give a quick way to test the order of a composite formula in a unit-conversion problem.

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REFERENCE CHECK ANSWERS

Meetings 1 through 3

1.C1

The domain is the integers $0, 1, \ldots, 12$. $F(8) = 10 + 24 = 34$ dollars. A passenger count of 8.5 is not allowed.

1.C2

The constant difference of 5 supports a linear model. Further observations with substantially different rates, or a context that changes the rule, would make the model questionable.

2.C1

$(30 - 12)/(7 - 1) = 18/6 = 3$ centimeters per day. This is the net height increase per day over the six-day interval.

2.C2

$(3 - 3)/(5 - 1) = 0$ meters per second. The endpoint heights agree, but the given interior height shows that the height changed.

3.C1

The input change is 5, so $18 + 4(7 - 2) = 38$.

3.C2

$f(4) = 2 + 5(4) = 22$ exactly. The interior linear estimate is $2 + 5(2) = 12$, but it is not guaranteed without more information.

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Meetings 4 through 6

4.C1

$f(x) = 17 + 4(x - 3) = 4x + 5$.

4.C2

18 dollars is a fixed fee and 2 dollars is added per item. $C(12) = 42$ dollars. The domain is the integers 0 through 40.

5.C1

$x^2 - 10x + 25 - 4 = (x - 5)^2 - 4$. The minimum is -4 at input 5.

5.C2

The first differences are $6, 2, -2, -6$ and the second differences are all -4. The parabola opens downward. Symmetry places the vertex at input 2, so the maximum output is 9.

6.C1

The maximum revenue is 900 dollars at the allowed price of 10 dollars. The price is the input; revenue is the output.

6.C2

The vertex input 2 is excluded. The allowed input nearest 2 is 4. Thus the greatest allowed output is $F(4) = 12$, at input 4.

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REFERENCE CHECK ANSWERS

Meetings 7 through 12

7.C

$13 = 4a + 5$, so $a = 2$. Check that the output rises by 8 when the input moves two units from the vertex.

8.C

The two-hour multiplier is 0.81. Its positive square root is 0.9, an hourly decrease of 10 percent.

9.C

On $[0, 2]$, $(x - 1)^2$ begins and ends at 1 yet dips to zero inside.

10.C

Try a new input, compare the measured value with the prediction and inspect the physical meaning of the turn. Three points with distinct inputs can determine a quadratic by construction.

11.C

$-4 = y - 19$ gives $y = 15$. The prediction is four units above the observation.

12.C

Their potential absolute error increases over the observed range. Examine the scale of the errors relative to the measurement size before choosing a new family.

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Meetings 13 through 18

13.C

Save a later reading until after choosing and fitting the model, then compare the new observation to the recorded prediction.

14.C

The output is 7 because the filled point includes input 4. The open point excludes that endpoint of the other branch.

15.C

$V(t) = 30 - 3(t - 4)$. It gives 30 at the change and zero at minute 14.

16.C

On the left the difference $x - 4$ is negative. Multiplying it by -1 gives its positive distance from zero, $4 - x$.

17.C

Look for a threshold where a rate or flat charge changes. Compute the amount accumulated at that threshold before writing the next branch.

18.C

Substitute original data, inspect boundary inputs and interpret units. An extreme at an unavailable input requires checking allowed alternatives.

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REFERENCE CHECK ANSWERS

Meetings 19 through 25

19.C

Two jobs take six hours. The pay is $18(6) + 10 = 118$ dollars.

20.C

Its numerical result is unknown from that table. If 5 is outside a stated domain, the evaluation is undefined instead.

21.C

$F \circ I$ works. For another, add 5 first and cube second. Checking the order gives the stated function.

22.C

Solve $x + 5 = -1$ to get $x = -6$. The point is $(-6, 6)$.

23.C

Solve $-2x = 8$, so the new point is $(-4, -3)$. The input reflects and its magnitude halves.

24.C

Use $5 + s/60$. At the new zero, the old clock already reads five minutes.

25.C

Trace a familiar input with units through the inner and outer rules. Check that the intermediate unit matches the unit expected at the next step.

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SOURCE NOTES

Texts and Southern Oregon settings

St. Mary's School Algebra II follows the 25-meeting Mod 1 sequence. The College Board Pre-AP Algebra 2 Course Guide (2024) supplies the framework. The lessons, problems and assessments are an SMS adaptation.

OpenStax reading

Based in part on OpenStax, Algebra and Trigonometry 2e, © 2026 Rice University. Read selected portions of sections 3.1–3.6, 4.1, 4.3, 5.1, 6.1, 6.7 and 6.8. The teacher guide identifies lesson-specific readings; section 6.7 is used here for exponential models, not its logarithmic example. Access for free at openstax.org. The SMS adaptation is distributed under CC BY-NC-SA 4.0.

Desmos Graphing Calculator • regression instructions

OpenStax Algebra and Trigonometry 2e

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Southern Oregon

The Bear Creek Greenway links communities including Ashland and Medford. Table Rocks has seasonal vernal pools. The BLM lists the Upper Table Rock trail to the top at 2.5 miles round trip. The National Park Service reports a greatest depth of 1,943 feet for Crater Lake. Those place facts are used in meetings 13, 15 and 24. All field readings, fees, business figures, schedules and model profiles in the exercises are invented classroom data.

Oregon State Parks • Scenic and Regional Trails

Bureau of Land Management • Table Rocks Natural History

Bureau of Land Management • Plan Your Visit to Table Rocks

National Park Service • Crater Lake



See the relationships.

A function connects two quantities. This volume develops the habit of moving between a story, a table, a graph, and an equation, then using those connections to decide what a result means.

Worked examples and short checks support independent study. Use this reference alongside the companion workbook for classwork, homework, and space to explain your reasoning.

STUDENT REFERENCE · VOLUME 1

Table Rock illustrations created for this SMS edition. Artistic interpretations of the Rogue Valley landscape.

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