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    "Welcome to Lab 2 of Data 8.3x!\n",
    "\n",
    "Today we will get some hands-on practice with linear regression.
You can find more information about this topic in\n",
    "[section 15.2](https://www.inferentialthinking.com/chapters/15/2/
Regression_Line)."
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    "# These lines import the Numpy and Datascience modules.\n",
    "import numpy as np\n",
    "from datascience import *\n",
    "\n",
    "# These lines do some fancy plotting magic.\n",
    "import matplotlib\n",
    "%matplotlib inline\n",
    "import matplotlib.pyplot as plots\n",
    "plots.style.use('fivethirtyeight')\n",
    "import warnings\n",
    "warnings.simplefilter('ignore', FutureWarning)\n",
    "warnings.simplefilter('ignore', UserWarning)\n",
    "\n",
    "# These lines load the tests.\n",
    "from gofer.ok import check"
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    "\n",
    "Let's revisit a question from lab 1. Last lab, we investigated
Old Faithful, a geyser in Yellowstone National Park in the central
United States. It's famous for erupting on a fairly regular schedule.
```

```
\n",
    "\n",
    "To recap, some of Old Faithful's eruptions last longer than
others. Today, we will use the same dataset on eruption durations and
waiting times to see if we can make predict the wait time from the
eruption duration using linear regression.\n",
    "\n",
    "The dataset has one row for each observed eruption.  It includes
the following columns:\n",
    "- **duration**: Eruption duration, in minutes\n",
    "- **wait**: Time between this eruption and the next, also in
minutes\n",
    "\n",
    "Run the next cell to load the dataset."
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    "Remember from last lab that we concluded eruption time and
waiting time are positively correlated. The table below called
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in standard units."
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    "wait_std = np.std(faithful.column(\"wait\"))\n",
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    "r"
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    "The correlation coefficient is the slope of the regression line
when the data are expressed in standard units.\n",
    "\n",
    "The next cell plots the regression line in standard units:\n",
    "\n",
    "$$\\text{waiting time (standard units)} = r \\times \
\text{eruption duration (standard units)}.$$"
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passing through two points.\"\"\"\n",
    "    dataset.scatter(x, y, label=\"data\")\n",
    "    xs, ys = zip(point_0, point_1)\n",
    "    plots.plot(xs, ys, label=\"regression line\")\n",
    "    plots.legend(bbox_to_anchor=(1.5,.8))\n",
    "\n",
    "plot_data_and_line(faithful_standard, \n",
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    "How would you take a point in standard units and convert it back 
to original units?  We'd have to \"stretch\" its horizontal position 
by `duration_std` and its vertical position by `wait_std`.\n",
    "\n",
    "That means the same thing would happen to the slope of the line.
\n",
    "\n",
    "Stretching a line horizontally makes it less steep, so we divide 
the slope by the stretching factor.  Stretching a line vertically 
makes it more steep, so we multiply the slope by the stretching 
factor.\n",
    "\n",
    "** Question 2.1 **<br/>\n",
    "What is the slope of the regression line in original units?\n",
    "\n",
    "(If the \"stretching\" explanation is unintuitive, consult 
section [15.2](https://www.inferentialthinking.com/chapters/15/2/
Regression_Line) in the textbook.)"
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    "#     r = correlation(t, x, y)\n",
    "#     return r * np.std(t.column(y))/np.std(t.column(x))\n",
    "\n",
    "slope = r * np.std(faithful.column(1)) /
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    "We know that the regression line passes through the point
`(duration_mean, wait_mean)`.  You might recall from high-school
algebra that the equation for the line is therefore:\n",
    "\n",
    "$$\\text{waiting time} - \\verb|wait_mean| = \\texttt{slope} \
\times (\\text{eruption duration} - \\verb|duration_mean|)$$\n",
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    "After rearranging that equation slightly, the intercept turns out
to be:"
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    "## 3. Investigating the regression line\n",
    "The slope and intercept tell you exactly what the regression line
looks like.  To predict the waiting time for an eruption, multiply the
eruption's duration by `slope` and then add `intercept`.\n",
    "\n",
    "** Question 3.1 ** <br/>\n",
```

```
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      "After an eruption lasting 5 minutes, we predict you'll wait
87.12260399842098 minutes until the next eruption.\n"
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    "two_minute_predicted_waiting_time = slope * 2 + intercept\n",
    "five_minute_predicted_waiting_time = slope * 5 + intercept\n",
    "\n",
    "# Here is a helper function to print out your predictions\n",
    "# (you don't need to modify it):\n",
    "def print_prediction(duration, predicted_waiting_time):\n",
    "    print(\"After an eruption lasting\", duration,\n",
    "          \"minutes, we predict you'll wait\",
predicted_waiting_time,\n",
    "          \"minutes until the next eruption.\")\n",
    "\n",
    "print_prediction(2, two_minute_predicted_waiting_time)\n",
    "print_prediction(5, five_minute_predicted_waiting_time)"
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    "Make predictions for the waiting time after each eruption in the
`faithful` table.  (Of course, we know exactly what the waiting times
were!  We are doing this so we can see how accurate our predictions
are.)  Put these numbers into a column in a new table called
`faithful_predictions`.  Its first row should look like this:\n",
    "\n",
    "|duration|wait|predicted wait|\n",
    "|-|-|-|\n",
    "|3.6|79|72.1011|\n",
    "\n",
    "*Hint:* Your answer can be just one line.  There is no need for a
`for` loop; use array arithmetic instead."
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in the dataset.  The residual is the difference (not the absolute 
difference) between the actual waiting time and the predicted waiting 
time.  Add the residuals to `faithful_predictions` as a new column 
called `\"residual\"`, naming the resulting table 
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confirms that it's reasonable to use linear regression for prediction.
It's true that there are two separate clouds; the eruption durations
seemed to fall into two distinct clusters.  But that's just a pattern
in the eruption durations, not a pattern in the relationship between
eruption durations and waiting times. A larger concern is that there
may be more positive than negative residuals in a particular region of
the horizontal axis. For both clusters, the points are distributed
fairly evenly above and below zero, which is a confirmation that the
association is mostly linear."
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    "The correlation coefficient is close to 1, implying that the
observed values are tightly clustered around the regression line.  The
residuals are overall small (close to 0) in comparison to the waiting
times.\n",
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    "We can see that visually by plotting the waiting times and
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    "plots.scatter(faithful_residuals.column(\"duration\"),
faithful_residuals.column(\"residual\"), label=\"residual\",
color=\"r\")\n",
    "plots.plot([2, 5], [two_minute_predicted_waiting_time,
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    "plots.legend(bbox_to_anchor=(1.7,.8));"
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Using this line, what is the predicted waiting time for an eruption
that lasts 0 minutes?  2.5 minutes?  An hour?"
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60.29850051058716 minutes until the next eruption.\n",
      "After an eruption lasting 60 minutes, we predict you'll wait
677.252880730765 minutes until the next eruption.\n"
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    "two_point_five_minute_predicted_waiting_time = slope * 2.5
+intercept\n",
    "hour_predicted_waiting_time = slope * 60 +intercept\n",
    "\n",
    "print_prediction(0, zero_minute_predicted_waiting_time)\n",
    "print_prediction(2.5,
```

```
two_point_five_minute_predicted_waiting_time)\n",
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    "## 5. Divide and Conquer"
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    "Let's see what happens if we treat the two clusters of
observations differently. It appears from the scatter diagram that
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another for durations between 3.5 and 5. A vertical line at 3 divides
the two clusters."
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    "    \"Convert any array of numbers to standard units.\"\n",
    "    return (any_numbers - np.mean(any_numbers)) /
np.std(any_numbers)  \n",
    "\n",
    "def standardize(t):\n",
    "    \"\"\"Return a table in which all columns of t are converted
to standard units.\"\"\"\n",
    "    t_su = Table()\n",
    "    for label in t.labels:\n",
    "        t_su = t_su.with_column(label + ' (su)',
standard_units(t.column(label)))\n",
    "    return t_su"
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    "Separately compute the regression coefficients *r* for all the
points with a duration below 3 **and then** for all the points with a
duration above 3. To do so, create a function that computes `r` from a
table and pass it two different tables of points, `below_3` and
`above_3`."
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    "def reg_coeff(t):\n",
```

```
    "    \"\"\"Return the regression coefficient for columns 0 &
1.\"\"\"\n",
    "    t_su = standardize(t)\n",
    "    return np.mean(t_su.column(0) * t_su.column(1))\n",
    "\n",
    "below_3 = faithful.where(\"duration\", are.below(3))\n",
    "above_3 = faithful.where(\"duration\", are.above(3))\n",
    "below_3_r = reg_coeff(below_3)\n",
    "above_3_r = reg_coeff(above_3)\n",
    "print(\"For points below 3, r is\", below_3_r, \"; for points
above 3, r is\", above_3_r)"
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    "Write functions `slope_of` and `intercept_of` below. \n",
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    "When you're done, the functions `wait_below_3` and `wait_above_3`
should each use a different regression line to predict a wait time for
```

```
a duration. The first function should use the regression line for all
points with duration below 3.2. The second function should use the
regression line for all points with duration above 3.2."
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    "def slope_of(t, r):\n",
    "    \"\"\"Return the slope of the regression line for t in
original units.\n",
    "    \n",
    "    Assume that column 0 contains x values and column 1 contains
y values.\n",
    "    r is the regression coefficient for x and y.\n",
    "    \"\"\"\n",
    "    return r * np.std(t.column (1))/np.std(t.column (0))\n",
    "\n",
    "def intercept_of(t, r):\n",
    "    \"\"\"Return the slope of the regression line for t in
original units.\"\"\"\n",
    "    s = slope_of(t, r)\n",
    "    return np.mean(t.column(1)) - s * np.mean(t.column(0))\n",
    "    \n",
    "below_3_a = slope_of(below_3, below_3_r)\n",
    "below_3_b = intercept_of(below_3, below_3_r)\n",
    "above_3_a = slope_of(above_3, above_3_r)\n",
    "above_3_b = intercept_of(above_3, above_3_r)\n",
    "\n",
    "def wait_below_3(duration):\n",
    "    return below_3_a * duration + below_3_b\n",
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    "def wait_above_3(duration):\n",
    "    return above_3_a * duration + above_3_b"
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each cluster separately, we discovered two different but similar
lines. Here are some natural questions to explore, if you want to
continue working with these data:\n",
    " * How much more accurate do we expect predictions to be using
two lines instead of one? Can we measure this improvement using
residuals?\n",
    " * Are the lines really different, or did they just come out
different due to chance because we have only a small number of
observations? How could we tell?\n",
    " * Could it be that the slopes of the lines are the same, but the
intercepts are different? "
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assignment, follow these steps...\n",
    "- **IMPORTANT** Before you do anything, **Save and Checkpoint** 
from the `File` menu. Please do this first before running the cell 
below,\n",
    "- **run all the tests and verify that they all pass** (the next 
cell has a shortcut for that), \n",
    "- **Review the notebook one last time** If you make any changes, 
please **Save and Checkpoint** again.\n",
    "- **Hit the Submit button** Your submission will be saved and 
grade will be posted when it's finished running."
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      "After an eruption lasting 0 minutes, we predict you'll wait 
33.474397022753344 minutes until the next eruption.\n",
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60.29850051058716 minutes until the next eruption.\n",
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677.252880730765 minutes until the next eruption.\n",
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3, r is 0.3727822255707511\n",
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    "if not globals().get('__GOFER_GRADER__', False):\n",
    "    display(grade_notebook('lab02.ipynb',
sorted(glob.glob('tests/q*.py'))))"
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