Arduino Programming Part 5: Functions Redux and Intro to Arrays

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Goals

Create functions for reading the conductivity sensor
- Only one function is needed (only one used at a time)
- Different functions have different features
- Change input data handling by using different functions
- Main program stays largely unchanged

Introduction to arrays
- Use arrays to store readings
- Compute average and standard deviation of the readings

Measuring salinity

Principle of operation
- Ions migrate to electrodes
- Ions exchange electrons with probes, causing current flow.
- Na+ is a spectator ion.
- Ion concentrations increase at electrodes when power is left on.
- Therefore, only turn on power during the time when reading is made. Leave it off otherwise.
Measuring salinity

Sensor circuit
- It's a voltage divider
- Resistance decreases as salt concentration increases
- Voltage across fixed resistor increases when sensor resistance decreases, i.e. when salt concentration increases

5V

salinity sensor (acts like variable resistor)

10 kΩ

Analog input

Study Questions

What is the voltage on the input pin for each of these conditions:
- If the electrical resistance of the water is zero?
- If the electrical resistance of the water is 10kΩ?
- If the electrical resistance of the water is ∞?

What is the input reading for each of those conditions?

If the resistance varied linearly with salinity, would the voltage vary linearly with salinity?

5V

salinity sensor (acts like variable resistor)

10 kΩ

Analog input

Programs for Reading the Salinity Sensor

1. Read one value at a time
   - Encapsulate the code in a function so it can be reused
2. Read multiple values and return an average
   - Code in a new function
3. Read multiple values and return average and standard deviation
   - Yet another function
   - Use an array to store readings, then compute statistics
   - Returning two values requires pointers

All three programs use the same circuit
**Measuring salinity**

**Measurement algorithm**
- Turn on the power by applying 5V to the voltage divider
- Wait for voltage transient to settle
- Read the voltage across fixed resistor
- Turn off the power

![Salinity sensor circuit diagram]

**Single reading of conductivity sensor**

```cpp
int power_pin = 4; // Digital I/O pin, Global variable

void setup()
{
  Serial.begin(9600);
  pinMode(power_pin, OUTPUT);
}

void loop()
{
  int input_pin = 2; // Analog input pin
  int reading;

  digitalWrite(power_pin, HIGH); // Turn on sensor
  delay(100); // wait to settle
  reading = analogRead(input_pin); // Measure voltage
  digitalWrite(power_pin, LOW); // Turn off power

  Serial.println(reading);
}
```

**Create a function to read the sensor**

**Why use functions?**
- Code in the loop function is just high level commands
  - Overall logic is easier to read and change
  - Reduce likelihood of error as overall code logic changes
- Keep details of sensor-reading contained in the function
  - Variables defined in the function are “local”
  - Details can change, e.g. to increase speed or reduce memory usage without changing the logic of the main function.
- Reuse the code in other projects: build a library of reusable components
Use a function to make a single reading

```c
int salinity_power_pin = 4;  // Digital I/O pin, Global variable
void setup()
{
  Serial.begin(9600);
  pinMode(power_pin, OUTPUT);
}
void loop()
{
  int salinity_input_pin = 2;  // Analog input pin
  int salinity;
  salinity = salinity_reading(salinity_power_pin, salinity_input_pin);
  Serial.println(salinity);
}
// ---------------------------------------------------
int salinity_reading(int power_pin, int input_pin) {
  int reading;
  digitalWrite(power_pin, HIGH);  // Turn on the sensor
  delay(100);  // Wait to settle
  reading = analogRead(input_pin);  // Read voltage
  digitalWrite(power_pin, LOW);  // Turn off the sensor
  return reading;
}
```

Encapsulate single reading in a function

```c
int salinity_power_pin = 4;  // Digital I/O pin, Global variable
void setup()
{
  Serial.begin(9600);
  pinMode(power_pin, OUTPUT);
}
void loop()
{
  int salinity_input_pin = 2;  // Analog input pin
  int salinity;
  salinity = salinity_reading(salinity_power_pin, salinity_input_pin);
  Serial.println(salinity);
}
// ---------------------------------------------------
int salinity_reading(int power_pin, int input_pin) {
  int reading;
  digitalWrite(power_pin, HIGH);  // Turn on the sensor
  delay(100);  // Wait to settle
  reading = analogRead(input_pin);  // Read voltage
  digitalWrite(power_pin, LOW);  // Turn off the sensor
  return reading;
}
```
Improve the function: Average several readings

Average is a measure of central tendency

\[ \bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \]

\[ \bar{x} = 675.1 \]

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Improve the function: Compute standard deviation

Standard deviation is a measure of spread

\[ \sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2} \]

\[ \sigma = 0.902 \]

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First improvement: Average several readings

This loop() function does not need to know the details

```c
int salinity_power_pin = 4;  // Digital I/O pin, Global variable

void setup()
{
  Serial.begin(9600);
  pinMode(power_pin, OUTPUT);
}

void loop()
{
  int salinity_input_pin = 2;  // Analog input pin
  int nave = 20;              // Number of readings to average
  float salinity;            // Float stores fractional reading from computed average

  salinity = salinity_reading_average( salinity_power_pin, salinity_input_pin, nave );
  Serial.print(salinity);
}
```
First improvement: Average several readings

Details are hidden in read_salinity_average

```c
float salinity_reading_average( int power_pin, int input_pin, int nave ) {
    int i;
    float reading, sum; // Use floats for more precision and to prevent overflow of sum
    sum = 0.0;
    for ( i=1; i<=nave; i++ ) {
        digitalWrite( power_pin, HIGH ); // Supply power to the sensor
        delay(100); // Wait for sensor to settle
        sum += analogRead( input_pin ); // Add reading to the running sum
        digitalWrite( power_pin, LOW ); // Turn off power to the sensor
        delay(10); // wait between readings
    }
    reading = sum/float(nave);
    return reading;
}
```

Compute average and standard deviation

Code is more complex
- C functions can only “return” one value
- C functions can modify inputs that are passed by address
- The address of a variable is its location in memory
- The address can be assigned to another variable called a pointer
- Pointers are challenging for the beginner

A simple example of pointers

```c
void loop() {
    int x = 2;
    int y;
    change_value(x, &y);
}

// -----------------------------------
void change_value( int a, int *b ) {
    *b = 2*a;
}
```
A simple example of pointers

```c
void loop() {
  int x = 2;
  int y;
  change_value(x, &y);
}

void change_value( int a, int *b ) {
  *b = 2*a;
}
```

Note: `change_value` does not return a value — its return type is `void`. When `change_value(x,&y)` is executed, the value stored in `y` is changed.

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Compute average and standard deviation

```c
void salinity_reading_stats( int power_pin, int input_pin, int nave, float *ave, float *stdev ) {
  int i, n;
  float sum;                       // Use a float to prevent overflow
  float reading[BUFFER_LENGTH];     // Array to store readings
  n = min( nave, BUFFER_LENGTH );   // Make sure we don’t over-run the data buffer
  // -- Store readings in an array
  for ( i=0; i<n; i++ ) {          // First array index is 0, last is n-1
    digitalWrite( power_pin, HIGH ); // Supply power to the sensor
    delay(100);                    // Wait for sensor to settle
    reading[i] = analogRead( input_pin ); // Add reading to the running sum
  }
  // -- Compute average and standard deviation.
  for ( sum=0.0, i=0; i<n; i++ ) { // Wait between readings
    sum += reading[i];
  }
  *ave = sum/float(nave);
  for ( sum=0.0, i=0; i<n; i++ ) { // First array index is 0, last is n-1
    sum += pow(reading[i] - *ave, 2);
  }
  *stdev = sqrt( sum/float(nave-1) );
}
```
int salinity_power_pin = 4; // Digital I/O pin
#define BUFFER_LENGTH 100 // Size of array to store readings for computation of ave and stdev
  // Reduce BUFFER_LENGTH to save memory if statistics are OK
  // with smaller sample size
void setup()
{
  Serial.begin(9600);
  pinMode(salinity_power_pin, OUTPUT);
}

void loop()
{
  int salinity_input_pin = 2;
  int nave = 20;
  float ave, stdev;
  salinity_reading_stats( salinity_power_pin, salinity_input_pin, nave, &ave, &stdev);
  Serial.print(ave);  Serial.print(", ");   Serial.println(stdev);
}