

# Project Euler: Problem 31

Nathan Marianovsky

**Problem (Coin Sums).** In England the currency is made of pound, £, and pence, p, and there are eight coins in general circulation:

1p, 2p, 5p, 10p, 20p, 50p, £1 (100p), £2 (200p)

It is possible to make £2 in the following way:

$$(1 \times £1) + (1 \times 50p) + (2 \times 20p) + (1 \times 5p) + (1 \times 2p) + (3 \times 1p)$$

How many different ways can £2 be made using any number of coins?

**Solution.** This problem is equivalent to finding the number of different solutions satisfying:

$$x_1 + 2x_2 + 5x_3 + 10x_4 + 20x_5 + 50x_6 + 100x_7 + 200x_8 = r \quad \text{where } x_i \geq 0 \quad \forall i \in \{1, 2, \dots, 8\}$$

In this problem specifically we want  $r = 200$ , but the calculations can be generalized to any given sum  $r$ . Now in order to solve this problem, consider the method of generating functions. Each variable will have a corresponding generating function that shows its possibilities:

$x_i$	Generating Function	Simplified Form
$x_1$	$g_{x_1}(t) = 1 + t + t^2 + \dots + t^r$	$g_{x_1}(t) = \frac{1-t^{r+1}}{1-t}$
$x_2$	$g_{x_2}(t) = 1 + t^2 + t^4 + \dots + t^r$	$g_{x_2}(t) = \frac{1-t^{r+2}}{1-t^2}$
$x_3$	$g_{x_3}(t) = 1 + t^5 + t^{10} + \dots + t^r$	$g_{x_3}(t) = \frac{1-t^{r+5}}{1-t^5}$
$x_4$	$g_{x_4}(t) = 1 + t^{10} + t^{20} + \dots + t^r$	$g_{x_4}(t) = \frac{1-t^{r+10}}{1-t^{10}}$
$x_5$	$g_{x_5}(t) = 1 + t^{20} + t^{40} + \dots + t^r$	$g_{x_5}(t) = \frac{1-t^{r+20}}{1-t^{20}}$
$x_6$	$g_{x_6}(t) = 1 + t^{50} + t^{100} + \dots + t^r$	$g_{x_6}(t) = \frac{1-t^{r+50}}{1-t^{50}}$
$x_7$	$g_{x_7}(t) = 1 + t^{100} + t^{200} + \dots + t^r$	$g_{x_7}(t) = \frac{1-t^{r+100}}{1-t^{100}}$
$x_8$	$g_{x_8}(t) = 1 + t^{200} + t^{400} + \dots + t^r$	$g_{x_8}(t) = \frac{1-t^{r+200}}{1-t^{200}}$

Giving an overall generating function:

$$g(t) = g_{x_1}(t)g_{x_2}(t) \dots g_{x_8}(t)$$

$$= \frac{(1-t^{r+1})(1-t^{2r+2})(1-t^{5r+5})(1-t^{10r+10})(1-t^{20r+20})(1-t^{50r+50})(1-t^{100r+100})(1-t^{200r+200})}{(1-t)(1-t^2)(1-t^5)(1-t^{10})(1-t^{20})(1-t^{50})(1-t^{100})(1-t^{200})}$$

The solution to the problem now corresponds to finding the coefficient of  $t^r$  in the power series expansion of the above generating function. For this problem specifically we want the coefficient of  $t^{200}$  which happens to be 73,682 when calculated using Mathematica and can actually be found faster by replacing the numerator with just 1 since the lowest degree of  $t$  after 0 is going to be exactly 201 making it all extra junk.