

# Additive Integer Partitions in R

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## Abstract

This vignette is based on [Hankin \(2005\)](#).

This vignette introduces the **partitions** package of R routines, for numerical calculation of integer partitions. Functionality for unrestricted partitions, unequal partitions, and restricted partitions is provided in a small package that accompanies this note; the emphasis is on terse, efficient C code. A simple combinatorial problem is solved using the package.

*Keywords:* Integer partitions, restricted partitions, unequal partitions, R.

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## 1. Introduction

A *partition* of a positive integer  $n$  is a non-increasing sequence of positive integers  $\lambda_1, \lambda_2, \dots, \lambda_r$  such that  $\sum_{i=1}^r \lambda_i = n$ . The partition  $(\lambda_1, \dots, \lambda_r)$  is denoted by  $\lambda$ , and we write  $\lambda \vdash n$  to signify that  $\lambda$  is a partition of  $n$ . If, for  $1 \leq j \leq n$ , exactly  $f_j$  elements of  $\lambda$  are equal to  $j$ , we write  $\lambda = (1^{f_1}, 2^{f_2}, \dots, n^{f_n})$ ; this notation emphasises the number of times a particular integer occurs as a part. The standard reference is [Andrews \(1998\)](#).

The partition function  $p(n)$  is the number of distinct partitions of  $n$ . Thus, because

$$5 = 4 + 1 = 3 + 2 = 3 + 1 + 1 = 2 + 2 + 1 = 2 + 1 + 1 + 1 = 1 + 1 + 1 + 1 + 1$$

is a complete enumeration of the partitions of 5,  $p(5) = 7$  (recall that order is unimportant: a partition is defined to be a non-increasing sequence).

Various restrictions on the nature of a partition are often considered. One is to require that the  $\lambda_i$  are distinct; the number of such partitions is denoted  $q(n)$ . Because

$$5 = 4 + 1 = 3 + 2$$

is the complete subset of partitions of 5 with no repetitions,  $q(5) = 3$ .

One may also require that  $n$  be split into *exactly*  $m$  parts. The number of partitions so restricted may be denoted  $r(m, n)$ .

## 2. Package partitions in use

The R ([R Development Core Team 2008](#)) package **partitions** associated with this paper may be used to evaluate the above functions numerically, and to enumerate the partitions they count. In the package, the number of partitions is given by  $P()$ , and the number of unequal partitions by  $Q()$ . For example,

```
> P(100)
```

```
[1] 190569292
```

agreeing with the value given by [Abramowitz and Stegun \(1965\)](#). The unequal partitions of an integer are enumerated by function `diffparts()`:

```
> diffparts(10)
```

```
[1,] 10 9 8 7 7 6 6 5 5 4
[2,]  0 1 2 3 2 4 3 4 3 3
[3,]  0 0 0 0 1 0 1 1 2 2
[4,]  0 0 0 0 0 0 0 0 0 1
```

where the columns are the partitions. Finally, function `restrictedpartitions()` enumerates the partitions of an integer into a specified number of parts.

## 2.1. A combinatorial example

Consider random sampling, with replacement, from an alphabet of  $a$  letters. How many draws are required to give a 95% probability of choosing each letter at least once? I show below how the **partitions** package may be used to answer this question exactly.

A little thought shows that the number of ways to draw each letter at least once in  $n$  draws is

$$N = \sum_{\lambda \vdash n; a} \frac{a!}{\prod_{i=1}^r f_i!} \cdot \frac{n!}{\prod_{j=1}^n \lambda_j!} \quad (1)$$

where the sum extends over partitions  $\lambda$  of  $n$  into exactly  $a$  parts; the first term gives the number of ways of assigning a partition to letters; the second gives the number of distinct arrangements.

The corresponding R idiom is to define a nonce function `f()` that returns the product of the two denominators, and to sum the requisite parts by applying `f()` over the appropriate restricted partitions. The probability of getting all  $a$  letters in  $n$  draws is thus  $N/a^n$ , computed by function `prob()`:

```
> f <- function(x){prod(factorial(x),factorial(tabulate(x)))}
> prob <- function(a,n){
+   jj <- restrictedparts(n,a,include.zero=FALSE)
+   N <- factorial(a)*factorial(n)*sum(1/apply(jj,2,f))
+   return(N/a^n)
+ }
```

In the case of  $a = 4$ , we obtain  $n = 16$  because `prob(4,15) ≈ 0.947` and `prob(4,16) ≈ 0.96`.

## 3. Conclusions

The **partitions** package was developed to answer the combinatorial word question discussed above: it does so using fast C code. Further work would include the enumeration of compositions and vector compositions.

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## References

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