Integration in the hyper2 package

Robin K. S. Hankin
Auckland University of Technology

Abstract

The **hyper2** package presented a new formulation of the **hyperdirichlet** package, offering speed advantages and the ability to deal with higher-dimensional datasets. However, **hyper2** was based on likelihood methods and as originally uploaded did not have the ability to integrate over the unit-sum simplex. This functionality has now been incorporated into the package which is documented here, by reproducing earlier analysis.

Keywords: Dirichlet distribution, hyperdirichlet, **hyper2**, combinatorics, R, multinomial distribution, constrained optimization, integration, simplex, unit-sum constraint.

1. Introduction

The **hyper2** package (Hankin 2017) presented a new formulation of the hyperdirichlet distribution (Hankin 2010) which offered speed advantages over the original **hyperdirichlet** package, and the ability to deal with higher-dimensional datasets. However, **hyper2** was based on likelihood methods and as originally uploaded did not have the ability to integrate over the unit-sum simplex. This functionality has now been incorporated into the package which is documented here, by reproducing earlier analysis.

2. Chess

Consider Table 1 in which matches between three chess players are tabulated; this dataset was analysed by Hankin (2010).

$$C\frac{p_1^{30}p_2^{36}p_3^{22}}{\left(p_1+p_2\right)^{35}\left(p_2+p_3\right)^{35}\left(p_1+p_3\right)^{18}}$$

(the symbol 'C' consistently stands for an undetermined constant). This likelihood function is provided in the **hyper2** package as the `chess` dataset:

```
> data(chess)
> chess

Topalov^30 * (Topalov + Anand)^-35 * (Topalov + Karpov)^-18 * Anand^36
* (Anand + Karpov)^-35 * Karpov^22
```

We can calculate the normalizing constant:

Topalov	Anand	Karpov	total
22	13	-	35
-	23	12	35
8	-	10	18
30	36	22	88

Table 1: Results of 88 chess matches (dataset `chess` in the **aylmer** package) between three Grandmasters; entries show number of games won up to 2001 (draws are discarded). Topalov beats Anand 22-13; Anand beats Karpov 23-12; and Karpov beats Topalov 10-8

```
> B(chess)

[1] 1.442828e-28
```

comparing well with the value given by the **hyperdirichlet** package of 1.47×10^{-28}. Hankin (2010) went on to calculate the p-value for $H_0\colon p = \left(\frac{1}{3}, \frac{1}{3}, \frac{1}{3}\right)$ as 0.395, a calculation which may be performed in the **hyper2** package as follows:

```
> f <- function(p){loglik(chess,indep(p)) > loglik(chess,c(1,1)/3)}
> probability(chess, disallowed=f,tol=0.01)

[1] 0.3785911
```

Again comparing well with the older result (smaller values of `tol` give closer agreement at the expense of increased computation time). Finally, we can calculate the probability that Topalov is a better player than Anand:

```
> T.lt.A <- function(p){p[1]<p[2]}
> probability(chess, disallowed=T.lt.A,tol=0.001)

[1] 0.7127539
```

again showing reasonable agreement with the 2010 value of 0.701.

3. Verification

In a breathtaking display of arrogance and/or incompetence, Hankin (2010) did not actually provide any evidence that the integration suite of **hyperdirichlet** was accurate. Here I compensate for that inexcusable lapse by comparing numerical results with analytical formulae. Consider the standard Dirichlet distribution:

$$\frac{p_1^{\alpha_1-1}\ldots p_k^{\alpha_k-1}}{B\left(\alpha_1,\ldots,\alpha_k\right)} \tag{1}$$

where it is understood that the $p_i > 0$ and $\sum p_i = 1$; here $B = \frac{\Gamma\sum\alpha_i}{\prod\Gamma\alpha_i}$ is the normalization constant. We can verify that `hyper2::B()` is operating as expected for the case $\alpha_1 = 1, \alpha_2 = 2, \alpha_3 = 3, \alpha_4 = 4$:

```
> prod(gamma(1:4))/gamma(sum(1:4))

[1] 3.306878e-05

> B(dirichlet(alpha=1:4))

[1] 3.306878e-05
```

Further, consider a Dirichlet distribution with $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 3$. Then, by symmetry, the probability that $p_1 < p_2$ should be exactly $\frac{1}{2}$:

```
> f <- function(p){p[1]<p[2]}
> H <- dirichlet(alpha=rep(2,4))
> probability(H,f,tol=0.1)

[1] 0.5045785
```

Further, $\mathsf{P}(p_1 < p_2 < p_3)$ should be exactly $\frac{1}{6}$:

```
> g <- function(p){(p[1]<p[2]) & (p[2]<p[3])}
> 1-probability(H,disallowed=g,tol=0.1)

[1] 0.1644873
```

4. More results: icons dataset

Consider the `icons` dataset, shown in table 2, and the following hypotheses, again following Hankin (2010), and reproduced here for convenience.

```
> data("oneill")                    # load the dataset
> icons

NB^32 * (NB + L + THC + OA)^-20 * (NB + L + THC + WAIS)^-15 * (NB + L +
OA + WAIS)^-9 * (NB + PB + THC + OA)^-18 * (NB + PB + THC + WAIS)^-18 *
(NB + PB + OA + WAIS)^-8 * L^24 * (L + PB + THC + OA)^-11 * (L + PB +
THC + WAIS)^-16 * (L + PB + OA + WAIS)^-18 * PB^30 * THC^24 * OA^14 *
WAIS^9

> maxp(icons)

        NB          L         PB        THC         OA       WAIS
0.25230411 0.17364433 0.22458188 0.17011281 0.11068604 0.06867083
```

For reference, the other hypotheses were:

icon						
NB	L	PB	THC	OA	WAIS	total
5	3	-	4	-	3	15
3	-	5	8	-	2	18
-	4	9	2	-	1	16
1	3	-	3	4	-	11
4	-	5	6	3	-	18
-	4	3	1	3	-	11
5	1	-	-	1	2	9
5	-	1	-	1	1	8
-	9	7	-	2	0	18
23	24	30	24	14	9	124

Table 2: Experimental results from O'Neill (2007) (dataset `icons` in the package): respondents' choice of 'most concerning' icon of those presented. Thus the first row shows results from respondents presented with icons NB, L, THC, and WAIS; of the 15 respondents, 5 chose NB as the most concerning (see text for a key to the acronyms). Note the "0" in row 9, column 6: this option was available to the 18 respondents of that row, but none of them actually chose WAIS

- $H_1\colon p_1 \geqslant \frac{1}{6}$
- $H_2\colon p_1 \geqslant \max\left\{p_2,\ldots p_6\right\}$
- $H_3\colon p_5 + p_6 \geqslant \frac{1}{3}$
- $H_4\colon \max\left\{p_5, p_6\right\} \geqslant \min\left\{p_1, p_2, p_3, p_4\right\}$

```
> f1 <- function(p){p[1] > 1/6}
> f2 <- function(p){p[1] > max(fillup(p)[-1])}
> f3 <- function(p){sum(fillup(p)[5:6]) > 1/3}
> f4 <- function(p){max(fillup(p)[1:2]) > min(fillup(p)[3:6])}
```

Here I will analyse just the first hypothesis, that is $H_1\colon p_1 \leqslant \frac{1}{6}$ using the integration facilities of the **hyper2** package, and compare with previous results. Here we perform a Bayesian analysis, made possible by the efficient coding of **hyper2**:

```
> probability(icons, disallowed=function(p){p[1] > 1/6}, tol=0.1)

[1] 0.01501733
```

See how the disallowed region is the *expected* bit of the parameter space. Thus the probability that the p_i are unexpected (that is, $p_1 < 1/6$) is about 1.5% or conversely, $P\left(H_1\right) \simeq 0.985$. The likelihood ratio reported was about 2.608, which would correspond to a p-value of about

```
> pchisq(2*2.608,df=1,lower.tail=FALSE)

[1] 0.02237997
```

or just over 2% under an asympotic distribution; thus this frequentist technique gives comparable strength of evidence for H_1 to the Bayesian approach.

5. Incomplete survey data

This section performs the analysis originally presented in Altham and Hankin (2010). The data, given here in table 4 arises from 69 medical malpractice claims, and are the two surgeons' answers to the question: was there a communication breakdown in the hand-off between physicians caring for the patient?

Reviewer 1	Reviewer 2			
	Yes	No	Missing	Total
Yes	26	1	2	29
No	5	18	9	32
Missing	4	4	0	8
Total	35	23	11	69

Table 3: Two surgeon reviews of malpractice claims data

Reviewer 1	Reviewer 2			
	Yes	No	Missing	Total
Yes	y_{11}	y_{10}	z_{1+}	$y_{1+} + z_{1+}$
No	y_{01}	y_{00}	z_{0+}	$y_{0+} + z_{0+}$
Missing	u_{+1}	u_{+0}	0	u_{++}
Total	$y_{+1} + u_{+1}$	$y_{+0} + u_{+0}$	z_{++}	n

Table 4: Notation for the data

We may implement an appropriate likelihood function as follows:

```
> H <- hyper2(d=4)
> pnames(H) <- c("t00","t10", "t01", "t11")
> H["t00"] <- 18
> H["t10"] <- 01
> H["t01"] <- 05
> H["t11"] <- 26
> H[c("t11","t10")] <- 2
> H[c("t01","t00")] <- 9
> H[c("t11","t01")] <- 4
> H[c("t10","t00")] <- 4
> H
```

```
t00^18 * (t00 + t10)^4 * (t00 + t01)^9 * t10 * (t10 + t11)^2 * t01^5 *
(t01 + t11)^4 * t11^26
```

(object `H` is provided as `handover` in the package). Then we may estimate the probability that reviewer 2 is more likely to give a 'yes' than reviewer 1 as follows:

```
> free <- maxp(H,give=TRUE)
> m <- fillup(free$par)
> names(m) <- pnames(H)
> m

       t00        t10        t01        t11
0.41954894 0.01798719 0.11127554 0.45118833

> free$value

[1] -64.14538
```

Then the constrained optimization:

```
> obj <- function(p){-loglik(H,p)}   # objective func
> gr  <- function(p){-gradient(H,p)} # gradient, needed for speed
> UI <- rbind(diag(3),-1)            # UI and CI specify constraints
> CI <- c(rep(0,3),-1)               # p_i >= 0 and sum p_i <= 1
```

We will test $H_A: p_2 < p_3$ using the method of support.

```
> ml_HA <- constrOptim(theta=c(0.1,0.2,0.1), f = obj,grad=gr,
+ ui = rbind(UI,c(0,1,-1)),   # p2 > p3
+ ci = c(CI,0))
> ml_HA$value

[1] 66.14453
```

Thus the support for H_A is

```
> ml_HA$value - free$value

[1] 130.2899
```

thus agreeing almost exactly with Altham and Hankin (2010).

References

Altham PME, Hankin RKS (2010). "Using recently developed software on a 2x2 table of matched pairs with incompletely classified data." *Journal of the Royal Statistical Society, series C*, **59**(2), 377–379.

Hankin RKS (2010). "A Generalization of the Dirichlet Distribution." *Journal of Statistical Software*, **33**(11), 1–18. URL http://www.jstatsoft.org/v33/i11/.

Hankin RKS (2017). "Partial rank data with the **hyper2** package: likelihood functions for generalized Bradley-Terry models." *The R Journal*, **9**(2), 429–439.

O'Neill S (2007). *An Iconic Approach to Representing Climate Change*. Ph.D. thesis, School of Environmental Science, University of East Anglia.

Affiliation:

Robin K. S. Hankin
Auckland University of Technology
E-mail: hankin.robin@gmail.com