

Adaptive Shrinkage and False Discovery Rates by Laplace Approximation

Matthew Stephens

2013/5/13

Outline

- Prelude

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- Allegro (ma non troppo)

Prelude

- Consider testing the null hypothesis $H_0 : \beta = 0$, vs the alternative $H_1 : \beta \neq 0$ in the logistic regression model:

$$\log \frac{p(Y_i = 1 | X_i = x)}{p(Y_i = 0 | X_i = x)} = \mu + x\beta$$

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- In genome-wide association studies, we may wish to do this for millions of different genetic variants (X).

Prelude

$$BF = \frac{\int p(Y|\mu, \beta, X) p_1(\mu, \beta|X) d\mu d\beta}{\int p(Y|\mu, \beta = 0, X) p_0(\mu|X) d\mu},$$

where p_0 and p_1 denote priors under H_0 and H_1 .

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- These integrals generally don't have closed forms, but being low-dimensional they are simple to approximate.
- For $p_1 : \beta \sim N(0, \phi^2)$, Wakefield, 2009 (see also Johnson, 2008) suggested a particularly simple *Approximate Bayes Factor* (ABF) based on the maximum likelihood estimate, $\hat{\beta}$, and its (estimated) standard error s .

Prelude

$$ABF = \sqrt{1 - k} \exp(0.5kT^2)$$

where $k := \phi^2/(s^2 + \phi^2)$ and $T := \hat{\beta}/s$.

- ABF arises if we assume $\hat{\beta}|s, \beta \sim N(\beta, s^2)$ and treat $\hat{\beta}$ as the observed “data”.

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- ABF arises if we assume $\hat{\beta}|s, \beta \sim N(\beta, s^2)$ and treat $\hat{\beta}$ as the observed “data”.
- Equivalently ABF can be derived as a “Laplace approximation”, approximating the likelihood $L(\beta)$ as Normal, centered on $\hat{\beta}$, with variance s^2 :

$$L(\beta) \propto \exp[-0.5(\beta - \hat{\beta})^2/s^2].$$

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 - The approximation is independent of prior.
 - Applicable to any regression where $\hat{\beta}$ and s are available.
 - Easily computed using results of standard software or published analyses (e.g. CI).
- A simple transformation of T can improve accuracy for small samples (analogous to t test vs Z test); Wen and Stephens, Arxiv.

Extensions of ABF

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- Eg In Wen and Stephens, we consider S subgroups, and approximate the BF for $H_0 : \beta_s = 0$ for all s , vs a general alternative $H_0 : \beta_s \neq 0$.

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- The problem: you have imperfect measurements of many “similar” things, and wish to estimate their values.
- Particularly common in genomics. For example, a very common goal is to compare the mean expression (activity) level of many genes in two conditions.

Example: Mouse Heart Data

- Data on 150 mouse hearts, dissected into left and right ventricle (courtesy Scott Schmemo, Marcelo Nobrega)

##	gene	lv1	lv2	rv1	rv2	genelength
## 1	Itm2a	2236	2174	9484	10883	1626
## 2	Sergef	97	90	341	408	1449
## 3	Fam109a	383	314	1864	2384	2331
## 4	Dhx9	2688	2631	18501	20879	4585
## 5	Ssu72	762	674	2806	3435	1446
## 8	Eif2b2	736	762	3081	3601	1565

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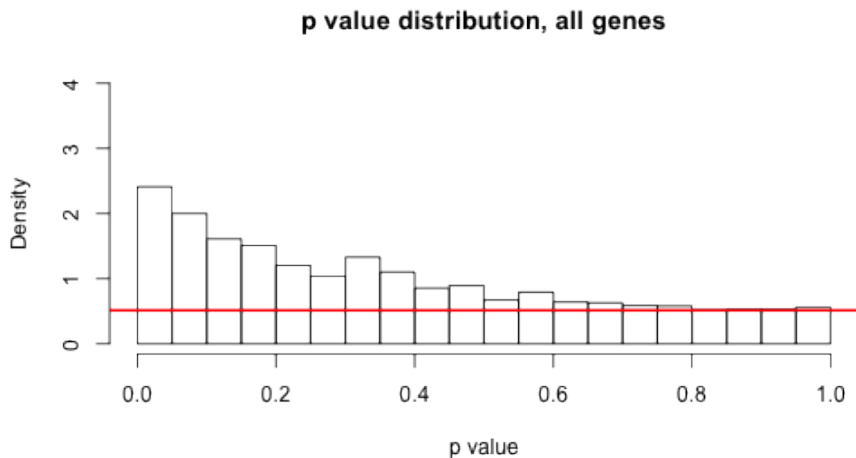
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 - Use the distribution of p values to estimate the false discovery rate (FDR) at a given threshold.

False Discovery Rates



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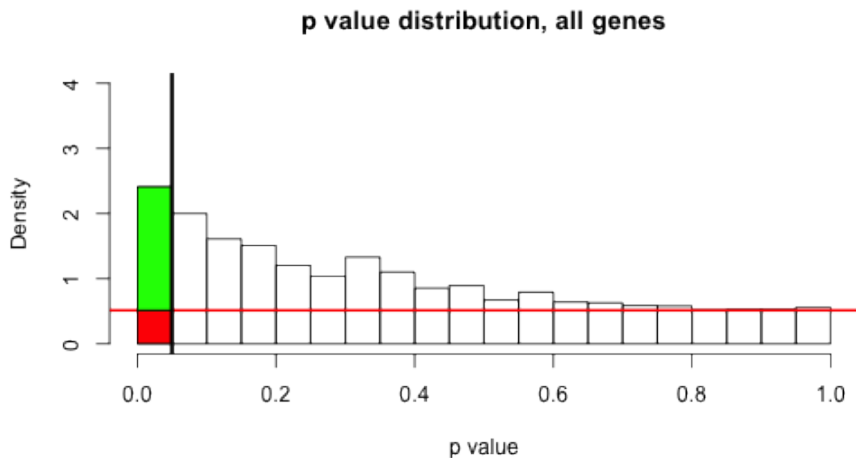
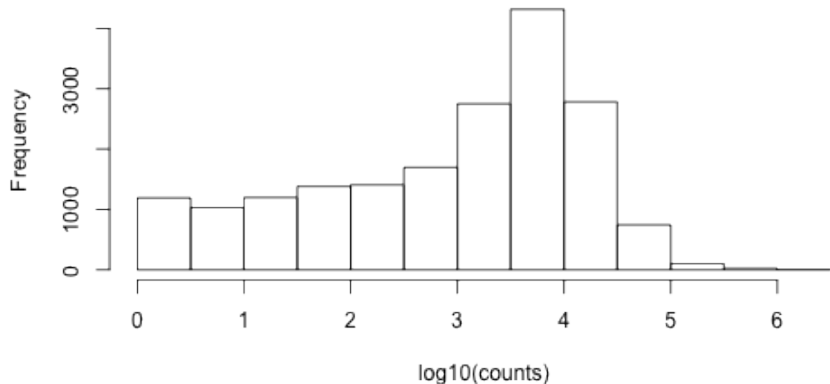


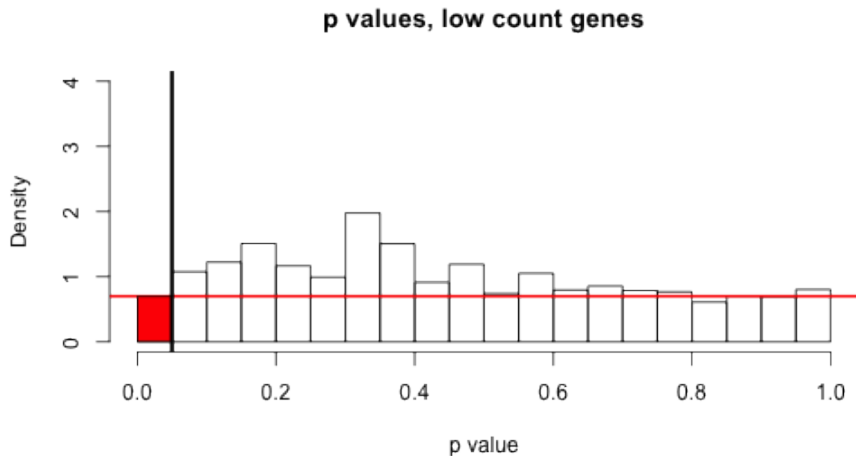
Figure : FDR=0.21

FDR problem: different genes have different precision/power

Counts vary considerably across genes



FDR problem: lower count genes, less power, add noise



FDR problem: higher count genes, more power

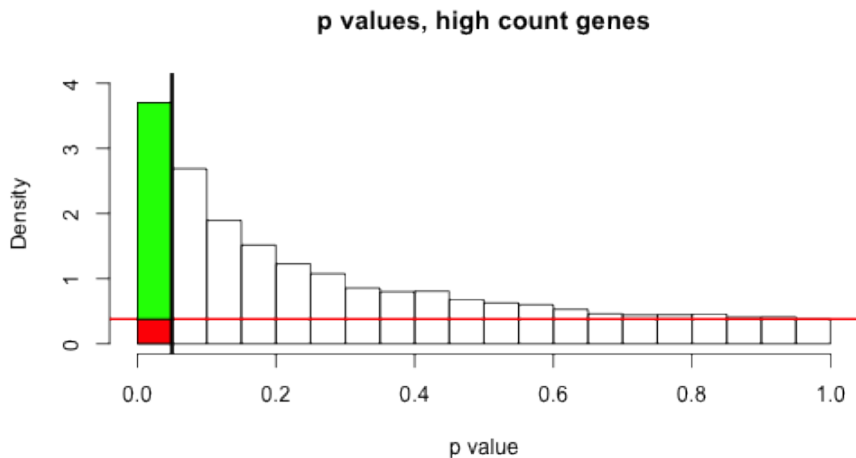


Figure : FDR=0.10

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- Possibly this is due, in part, to the lack of a simple, flexible, and generic implementation?

Generic adaptive shrinkage via Laplace approximation

- Summarize data on each gene by two numbers, $\hat{\beta}_j$ and its standard error s_j . (a la Wakefield; Greenland and Robins 1991)

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- Letting $g(\cdot; \pi)$ be a mixture of normal distributions provides both flexibility, and analytic calculations.
 - very small variances can capture effects that are “effectively” zero.

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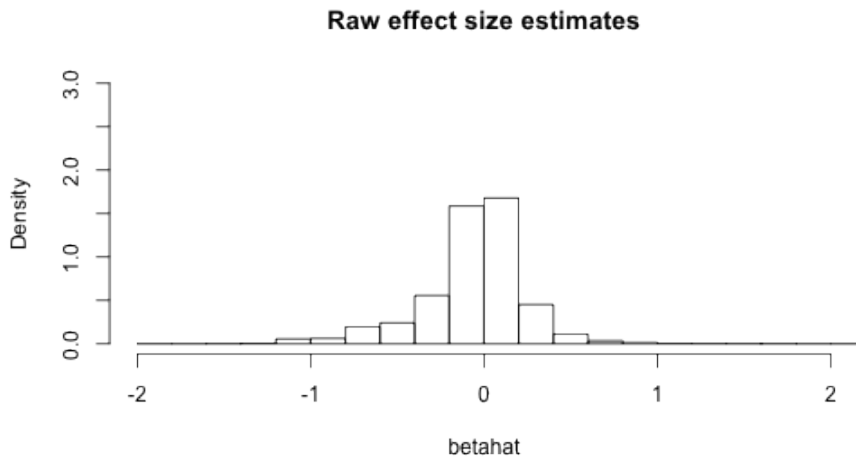
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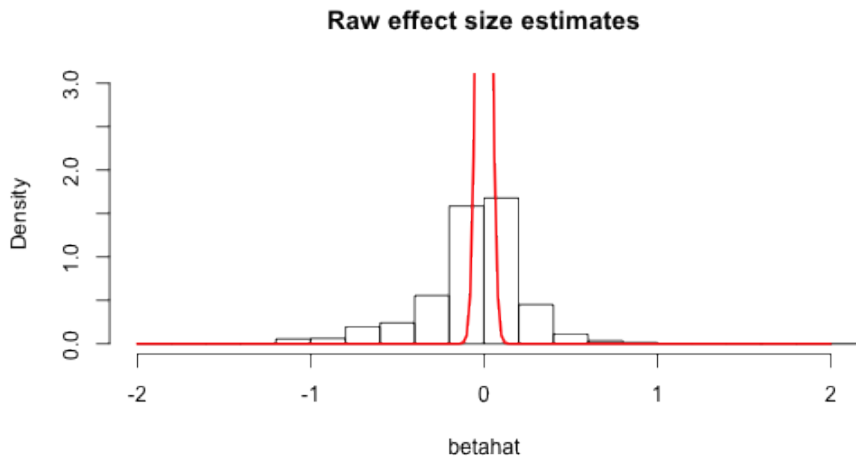
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- And $p(\beta_j > 0 | \hat{\beta}, s, \hat{\pi})$ can be used to identify j for which the sign of β_j can be confidently determined (analogous to test of $\beta_j = 0$; Gelman et al, 2012).
- Because π is estimated from the data, the amount of shrinkage is adaptive to the data. And because of the role of s_j , the amount of shrinkage adapts to the information on each gene.

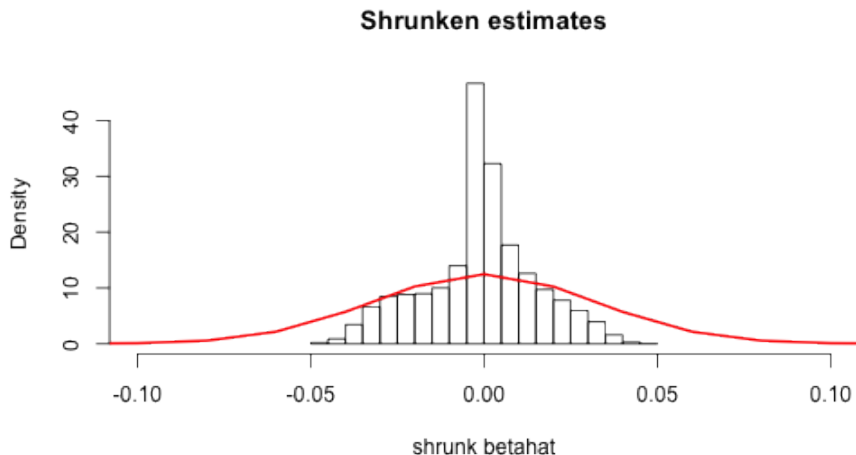
Example: ASH applied to mouse data



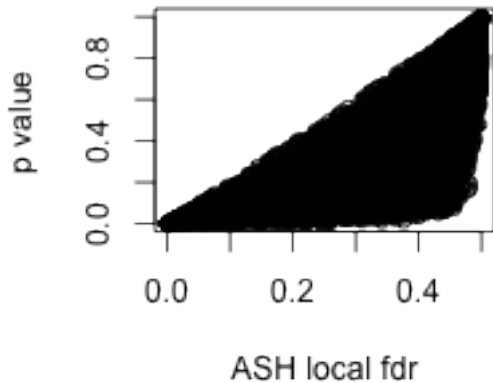
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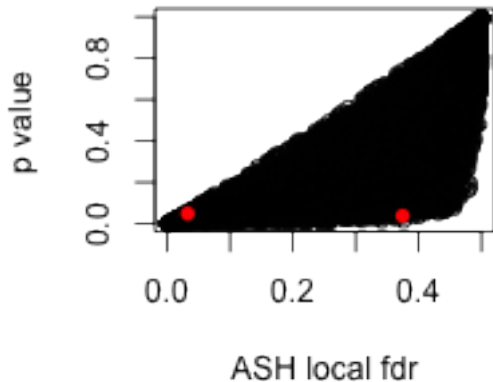
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Shrinkage is adaptive to information



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##	gene	lv1	lv2	rv1	rv2	pval	zdat.ash\$localfdr
## 19422	Mgat5b	7	10	320	452	0.03795	0.37448
## 20432	Sec63	1042	1034	5496	6649	0.04908	0.03251

Summary: FDR vs ASH

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- Both are generic and modular: once you have the summary data, you can forget where they came from.
- But by using two numbers ($\hat{\beta}, s$) instead of one (p values) precision of different measurements can be better accounted for.
- ASH borrows information for estimation, as well as testing.

Next steps?

- Extend to allow $g(\cdot; \pi)$ to depend on covariates X .

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- Extend to allow for correlations in the measured $\hat{\beta}_j$.

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- And to the NIH for funding, and i-like for inviting me.

Reproducible research

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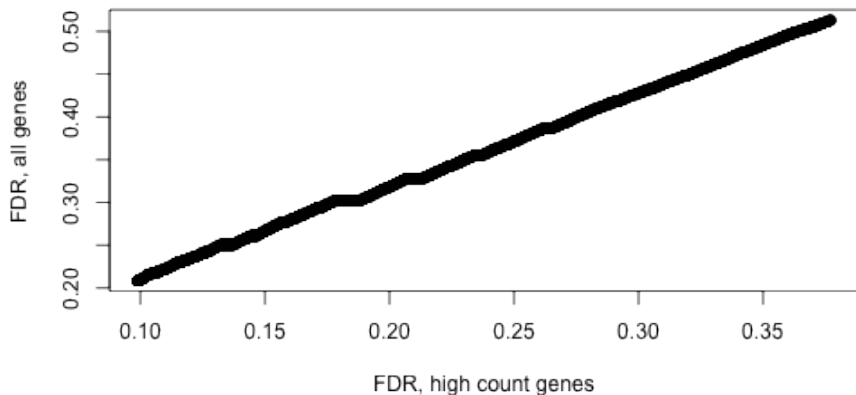
Pandoc Command used

```
pandoc -s -S -i -template=my.beamer -t beamer -V theme:CambridgeUS  
-V colortheme:beaver ilike-slides.md -o ilike-slides.pdf
```

Here is my session info:

```
print(sessionInfo(), locale = FALSE)  
  
## R version 2.15.1 (2012-06-22)  
## Platform: x86_64-apple-darwin9.8.0/x86_64 (64-bit)  
##  
## attached base packages:  
## [1] stats      graphics  grDevices  utils      datasets  metho  
##  
## other attached packages:  
## [1] qvalue_1.30.0 knitr_1.1  
##  
## loaded via a namespace (and not attached):  
## [1] codetools_0.2-8 digest_0.6-3 evaluate_0.4-3 formatR_0.1-1
```

FDRs for higher count genes affected by lower count genes



Some odd things in the data

