A very short introduction into the aws package

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This document illustrates the capabilities of the aws package. For a more comprehensive overview and more realistic examples we refer to Polzehl, Papafitsoros, and Tabelow 2020 and appendix A of Polzehl and Tabelow 2019.

The package contains functions for adaptive smoothing (filtering) in various settings, including regular (and irregular) designs in 1D, 2D, 3D and SE(3), for univariate and vector valued observations.

The code in this vignette is restricted to 1D and 2D examples due to limited computation time.

1 Some artificial data

First, we generate some artificial examples:

The first example employs a local constant univariate regression function

\begin{verbatim}
> library(aws)
> fofx1 <- c(rep(0,25),rep(-1,20),rep(1,20), rep(-2,10),rep(2,5),
+          rep(-1,25),rep(-.5,30),rep(0,35))
> set.seed(1)
> y1 <- rnorm(fofx1,fofx1,.3)
\end{verbatim}

The second example uses a local constant image

\begin{verbatim}
> u1 <- matrix(0,64,64)
> ind0 <- seq(0,1,length=64)
> ind <- outer(ind0^2,ind0^2,"+")
> u1[ind > .95] <- u1[ind >.95] + 2
> u1[ind < .6] <- u1[ind <.6] - 2
> u1[ind < .35] <- u1[ind <.35] +3
> u1[ind < .05] <- u1[ind <.05] +3
> u1 <- u1*(1-2*outer(ind0,ind0,">"))
> z1 <- u1+rnorm(u1)
\end{verbatim}

In the third example a smooth image is added leading to a locally smooth image

\begin{verbatim}
> u2 <- u1+5*ind
> z2 <- u2+rnorm(u1)
\end{verbatim}
2 Nonparametric smoothing

Nonparametric smoothing using FFT is implemented in function kernsm for 1D, 2D and 3D data.

```r
> yhat0 <- kernsm(y1, h=10)
```

3 Adaptive weights smoothing

Function aws implements the structural adaptive smoothing methods developed in Polzehl and Spokoiny 2000 and Polzehl and Spokoiny 2006.

```r
> yhat1 <- aws(y1, hmax=100)
> par(mfrow=c(1,3), mar=c(3,3,3,1), mgp=c(2,1,0))
> plot(y1)
> lines(yhat1@theta, col=2)
> lines(fofx1, col=3)
> title("AWS estimate")
> plot(yhat1@ni)
> title("Sum of weights")
> plot(y1)
> lines(kernsm(y1,.609)@yhat, col=2)
> lines(fofx1, col=3)
> title("MSE optimal kernel estimate")
```

The left figure shows the data, estimated regression function (red) in comparison to the true function (green). The central panel provides, for each design point, the sum of weights employed in the last step of the AWS algorithm, while the right panel illustrates the behaviour of a kernel estimate with MSE optimal bandwidth.

For the 2D examples we employ both the functions aws and paws. The latter function implements the patchwise adaptive weights algorithm described in PoPaTh18.

```r
> setCores(2)
> zhat1a <- aws(z1, hmax=8)
> zhat1b <- paws(z1, hmax=10, patchsize=1)
```
The Figure illustrates the results obtained using both methods in comparison with the noisy original and the true image.

To illustrate the dependence of the obtained reconstruction quality we use the second, locally smooth, 2D example.

```r
> zhat2a <- aws(z2, hmax=8)
> zhat2b <- paws(z2, hmax=10)

> par(mfrow=c(2,3), mar=c(3,3,3,1), mgp=c(2,1,0))
> title("Noisy original")
> title("AWS reconstruction")
> title("PAWS reconstruction")
> title("AWS sum of weights")
> title("PAWS sum of weights")
```
Note that AWS enforces the structural assumption of a local constant image if large maximal bandwidths are used. This drawback is overcome in PAWS which allows for smooth image gradients and prefers smooth discontinuities.

Both functions handle 1D, 2D and 3D images.

4 Intersection of confidence intervals

The package also contains functions implementing the Intersection of confidence intervals approach from Katkovnik, Egiazarian, and Astola 2006. The approach is based on adaptation techniques that combine results obtained by kernel smoothing for a sequence of bandwidths and for orientation (sector) dependent support of the kernel.

> zhat1c <- kernsm(z1, .9)@yhat
> zhat1d <- ICIsmooth(z1, hmax=8, thresh=.8, presmooth=TRUE)@yhat
> zhat1e <- ICIcombined(z1, hmax=8, nsector=8, thresh=.8, +
                       presmooth=TRUE)@yhat

We here apply sets of parameters choosen to provide good MSE for reconstruction results.
5 Non-local means filter

For comparisons the NL Means algorithm (Coupé et al. 2008), (Coupé et al. 2012) in 1D, 2D and 3D is provided with function \texttt{nlmeans}.

\begin{verbatim}
> zhat1f <- nlmeans(z1, .85, 1, searchhw=6)$theta
\end{verbatim}

6 Total variation methods

Additionally functions \texttt{TV_denoising} and \texttt{TGV_denoising} implement total variation (Rudin, Osher, and Fatemi 1992) and total generalized variation (Bredies, Kunisch, and Pock 2010) methods for image denoising in 2D.

\begin{verbatim}
> zhat1f <- TV_denoising(z1, .93)
238 Chambolle-Pock iterations completed
> zhat1g <- TGV_denoising(z1, .92, 4)
1000 Chambolle-Pock iterations completed
\end{verbatim}
The figure provides reconstructions for the first (local constant) 2D example using NL Means, TV and TGV denoising. For all three methods parameters are optimized for the data at hand.

7 Other content

The package aws also contains functions for locally adaptive variance estimation, versions of AWS and PAWS for vector valued data (used e.g. in package qMRI) and AWS methods for data in SE(3) (these methods are used for smoothing of diffusion weighted data in package dti). Most of the computationally intensive code is parallelized using openMP.

References


