

# Eine Woche, ein Beispiel

## 12.3. cheating sheet for six functors

Ref: <https://people.mpim-bonn.mpg.de/scholze/SixFunctors.pdf>

$$\begin{array}{ccc} G & \xrightarrow{\tau} & \mathcal{F}' \\ \downarrow & \searrow & \downarrow \\ Y & \xrightarrow{f} & X \end{array}$$

$$\begin{array}{ccc} Y' & \xrightarrow{f'} & X' \\ g' \downarrow & & \downarrow g \\ Y & \xrightarrow{f} & X \end{array}$$

$$\begin{aligned} f^* &\dashv f_* \\ - \otimes \mathcal{F} &\dashv \underline{\mathrm{Hom}}(\mathcal{F}, -) \\ f_! &\dashv f^! \end{aligned}$$

$$\begin{aligned} f^*(- \otimes -) \\ f^*(\mathcal{F} \otimes \mathcal{F}') &\cong f^* \mathcal{F} \otimes f^* \mathcal{F}' \\ f_* \underline{\mathrm{Hom}}(f^* \mathcal{F}, \mathcal{G}) &\cong \underline{\mathrm{Hom}}(\mathcal{F}, f_* \mathcal{G}) \end{aligned}$$

$$\begin{array}{ccc} & \otimes & \\ f^* & \xrightarrow{\quad} & f_! \\ \text{bc: } f^* g_! & \cong & g'_! f'^* \\ & g'_! f_* & \cong f_* g'_! \end{array}$$

proj formula

$$f_!(f^* \mathcal{F} \otimes \mathcal{G}) \cong \mathcal{F} \otimes f_! \mathcal{G}$$

$$f_* \underline{\mathrm{Hom}}(\mathcal{G}, f^* \mathcal{F}) \cong \underline{\mathrm{Hom}}(f_* \mathcal{G}, \mathcal{F})$$

$$f^! \underline{\mathrm{Hom}}(\mathcal{F}, \mathcal{F}') \cong \underline{\mathrm{Hom}}(f^* \mathcal{F}, f^! \mathcal{F}')$$

These extra formulas (compatibilities) come from the upgrade of adjunction formula to internal Hom. To upgrade the adjunction between tensor product and internal Hom, one don't need extra formula, except the association law of tensor product.

$$\begin{aligned} I: f^* &= f^! \\ P: f_* &= f_! \end{aligned}$$

$$p: X \rightarrow pt$$

$$H^i(X; \mathbb{Z}) := p_* p^* \mathbb{1}$$

$$H_c^i(X; \mathbb{Z}) := p_! p^* \mathbb{1}$$

$$H^i(X; \mathbb{Z}) := p_! p^! \mathbb{1}$$

$$H^{BM}_i(X; \mathbb{Z}) := p_* p^! \mathbb{1}$$

$$H^i(X; \mathcal{F}) := p_* \mathcal{F}$$

$$H_c^i(X; \mathcal{F}) := p_! \mathcal{F}$$

$$H^i(X; \mathcal{F}) := p_! (p^! \mathbb{1} \otimes \mathcal{F})$$

$$H^{BM}_i(X; \mathcal{F}) := p_* (p^! \mathbb{1} \otimes \mathcal{F})$$

$$= R\Gamma(X; \mathcal{F})$$

$$= H_c^i(X; p^! \mathbb{1} \otimes \mathcal{F})$$

$$= H^i(X; p^! \mathbb{1} \otimes \mathcal{F})$$

App 1. (Künneth formula)

$$H_c^i(X; \mathcal{F}) \otimes H_c^j(Y; \mathcal{G}) \cong H_c^{i+j}(X \times Y; \mathcal{F} \otimes \mathcal{G})$$

$$\text{reduced to: } p_{X!} \mathcal{F} \otimes p_{Y!} \mathcal{G} \cong p_! (p_X^* \mathcal{F} \otimes p_Y^* \mathcal{G})$$

$$\begin{array}{ccc} X \times Y & \xrightarrow{p_2} & Y \\ p_! \downarrow & \searrow p & \downarrow p_Y \\ X & \xrightarrow{p_X} & * \end{array}$$

App 2. (Poincaré duality)

$X$ : a cpt oriented mfd of dim  $d$ , then

$$-^\vee = \underline{\mathrm{Hom}}_{\mathcal{D}(\mathbb{Z})}(-, \mathbb{Z})$$

proper

$$p^! \mathbb{Z} \cong \mathbb{Z}[d] \text{ locally (Verdier duality)}$$

$$p^! \mathbb{Z} \cong \mathbb{Z}[d] \text{ globally}$$

$$H^i(X; \mathbb{Z})[d] \cong H^i(X; \mathbb{Z})^\vee$$

$$\text{reduced to: } p_* \underline{\mathrm{Hom}}(A, p^* B \otimes p^! \mathbb{1}) \cong \underline{\mathrm{Hom}}(p_! A, B)$$

ff. fully faithful  
pi. preserve injectives. (内射)  
ie. inj sheaf  $\rightarrow$  inj sheaf

$\pi_i$ : preserve injectives. (内射)

ie.  $\text{inj sheaf} \leadsto \text{inj sheaf}$

Just by checking the stalk & taking the dual, one gets

Here,  $H_{-1}(S'; \mathbb{Q}) = \mathbb{Q}$  for convenience of index.

$$\begin{array}{ccccccc} R\Gamma(x, z; \mathcal{F}) & \longrightarrow & R\Gamma(X; \mathcal{F}) & \longrightarrow & R\Gamma(z; \mathcal{F}|_z) & \xrightarrow{+1} & \\ R\Gamma(x, u; \mathcal{F}) & \longrightarrow & R\Gamma(X; \mathcal{F}) & \longrightarrow & R\Gamma(u; \mathcal{F}|_u) & \xrightarrow{+1} & \\ R\Gamma_z(x; \mathcal{F}) & & & & & & \end{array}$$

Taking  $R_{\pi_X, !}$

$$\begin{array}{l} \text{When } \mathcal{F} = \underline{Q}_x, \quad H_c^*(U) \longrightarrow H_c^*(X) \longrightarrow H_c^*(Z) \xrightarrow{+1} \\ \quad H_c^*(Z, i^* \underline{Q}_x) \longrightarrow H_c^*(X) \longrightarrow H_c^*(X, Rj_* \underline{Q}_u) \xrightarrow{+1} \\ \text{When } \mathcal{F} = \text{ID}_X, \quad H_*(U) \longrightarrow H_*(X) \longrightarrow H_*(X, U) \xrightarrow{+1} \\ \quad H_*(Z) \longrightarrow H_*(X) \longrightarrow H_*(X, Z) \xrightarrow{+1} \end{array}$$

$H^i$  &  $H_i$  are invariant under homotopy equivalence,  
while  $H_e$  &  $H^{BM}$  are better for assembly.

$$\begin{array}{ccccccc}
 j_! \mathcal{F} & \longrightarrow & Rj_* \mathcal{F} & \longrightarrow & i_! i^* Rj_* \mathcal{F} & \xrightarrow{+1} & \\
 i^! \mathcal{F} & \longrightarrow & i^* \mathcal{F} & \longrightarrow & i^* Rj_* j^! \mathcal{F} & \xrightarrow{+1} & 
 \end{array}$$

local cohomology compares the difference between stalks and costalks.

$$\begin{array}{ccccccc}
 i^! j_! j^* \mathcal{F} & \longrightarrow & i^! \mathcal{F} & \longrightarrow & i^* \mathcal{F} & \xrightarrow{+1} & \\
 i_* i^! j_! \mathcal{F} & \longrightarrow & j_! \mathcal{F} & \longrightarrow & Rj_* \mathcal{F} & \xrightarrow{+1} & 
 \end{array}$$

Cor.  $i^* Rj_* \cong i^! j_! [1]$ .

$$i_* R\underline{\mathrm{Hom}}(i^* \mathcal{F}, i^! \mathcal{G}) \longrightarrow R\underline{\mathrm{Hom}}(\mathcal{F}, \mathcal{G}) \longrightarrow Rj_* R\underline{\mathrm{Hom}}(j^* \mathcal{F}, j^! \mathcal{G}) \xrightarrow{+1}$$

Quick reminder.

$\pi: Y \longrightarrow \{*\}$	$f^*$	$f^!$	$Rf_!$	$Rf_*$
$\iota_p: \{p\} \hookrightarrow X$	$\underline{\mathbb{Q}}_Y$	$\mathcal{O}_{r_Y}[\dim_{\mathbb{R}} Y]$	$H_c(Y; G)$	$H(Y, G)$
$i: Z \hookrightarrow X$	$\mathcal{F}_p$	$\mathcal{F}_p, \text{costalk}$	$sky_p(\mathcal{Q})$	
$j: U \hookrightarrow X$	$\mathcal{F} _Z$	$i^! \mathcal{F} = R\Gamma_Z^*(\mathcal{F})$	$sky_Z(G)$	
$f: X \sqcup X \longrightarrow X$	$\mathcal{F} _U$		$j^! G$	$Rj_* G$
$f: \mathbb{C} \xrightarrow{z^2} \mathbb{C}$	$(\mathcal{F}, \mathcal{F})$		$\mathcal{F}_1 \oplus \mathcal{F}_2$	
$\mathcal{F} = \mathcal{G} = \underline{\mathbb{Q}}_{\mathbb{C}}$	$\underline{\mathbb{Q}}_{\mathbb{C}}$		$\mathbb{Q}^2 \xrightleftharpoons[\begin{pmatrix} 2 \\ -2 \end{pmatrix}]{\begin{pmatrix} 1, -1 \end{pmatrix}} \mathbb{Q}$	
$f: \mathbb{C} \xrightarrow{z^2} \mathbb{C}$			$\mathbb{Q}^3 \xrightleftharpoons[\text{ }]{\begin{pmatrix} 0 & -1 & 0 \\ 0 & 1 & -1 \end{pmatrix}} \mathbb{Q}^2$	
$\mathcal{F} = \mathcal{G} = \underline{\mathbb{Q}}_{\mathbb{C}}$	$\underline{\mathbb{Q}}_{\mathbb{C}}$			

## Application

### One point compactification

The rigorous name is "Alexandroff extension". Just be careful that we may not be able to define  $f_!$  for general topological spaces.

$$\begin{array}{ccc} X & \xrightarrow{\iota} & \bar{X} \\ \pi \searrow & & \swarrow \bar{\pi} \\ & \{*\} & \end{array}$$

$$\begin{aligned} H_c^*(X) &= R\pi_* \pi^* \mathbb{Z} \\ &= R\bar{\pi}_* \iota_* \iota^* \pi^* \mathbb{Z} \\ &= R\bar{\pi}_* (\iota_* \iota^* \mathbb{Z}_{\bar{X}}) \\ &= H^*(\bar{X}, \{*\}; \mathbb{Z}) \end{aligned}$$

$$\begin{aligned} H_*^{BM}(X) &= R\pi_* \pi^! \mathbb{Z} \\ &= R\bar{\pi}_* \iota_* \iota^! \pi^! \mathbb{Z} \\ &= R\bar{\pi}_* (\iota_* \iota^! \mathbb{Z}) \\ &= \text{cone}(R\bar{\pi}_* i_! i^! \pi^! \mathbb{Z} \longrightarrow R\bar{\pi}_* \pi^! \mathbb{Z}) \\ &= H_*(\bar{X}, \{*\}; \mathbb{Z}) \end{aligned}$$

Originally, this is another def of cpt supp coh & BM homology.

## Vector bundle with $\mathbb{G}$ -functors.

Goal: Define Thom class & Euler class as in [GTM82, §6]

[GTM82]: Raoul Bott, Loring W. Tu, Differential Forms in Algebraic Topology, 1982  
<https://link.springer.com/book/10.1007/978-1-4757-3951-0>

$$\begin{array}{ccc}
 H_c^*(F) \longleftarrow H_{cv}^*(E) & \xrightarrow{s^*} & H^*(B) \\
 \downarrow \cong & & \\
 H^{*-r}(B) & & 
 \end{array}
 \quad
 \begin{array}{ccc}
 \text{generator} \in H_c^r(F) & \xleftarrow{\quad} & \Phi \in H_{cv}^r(E) \\
 & & \downarrow \\
 & & 1 \in H^0(B)
 \end{array}
 \quad
 \begin{array}{ccc}
 & & \xrightarrow{eu_B} H^r(B) \\
 & & \downarrow \\
 & & 1
 \end{array}$$

Setting

$\pi: E \rightarrow B$  oriented v.b. with fiber  $F \cong \mathbb{R}^r$   
 $\beta_F$ : one point compactification ( $\mathbb{R}^n \subset S^n$ )  
 $\beta_E$ : fiberwise compactification  
 $\pi_X: X \rightarrow \{*\}$

$$\begin{array}{ccccc}
 & \bar{F} & \xrightarrow{l_{\bar{F}}} & \bar{E} & \\
 \beta_F \nearrow & & & & \nearrow \beta_E \\
 F & \xrightarrow{l_F} & E & & \\
 \pi_F \downarrow & & \downarrow \pi & & \downarrow \bar{\pi} \\
 \{p\} & \xrightarrow{l_p} & B & & 
 \end{array}$$

Def  $H_{cv}^*(E) \stackrel{\text{compact vertical}}{=} H^*(\bar{E}, \bar{E} - E)$

$$\begin{aligned}
 &= R\pi_{E,*} \beta_{E,!} \beta_E^! \mathbb{Z}_{\bar{E}} \\
 &= R\pi_{B,*} (R\bar{\pi}_! \beta_{E,!}) (\beta_E^* \mathbb{Z}_{\bar{E}}) \\
 &= R\pi_{B,*} R\pi_! \mathbb{Z}_E
 \end{aligned}$$

Ex. Construct the following canonical maps by six functors.

$$\begin{array}{ccc}
 H^*(\bar{F}, \bar{F} - F) \longleftarrow H^*(\bar{E}, \bar{E} - E) & & R\pi_{\bar{F},*} \beta_{F,!} \mathbb{Z}_F \longleftarrow R\pi_{E,*} \beta_{E,!} \mathbb{Z}_E \\
 \parallel \scriptstyle S & & \parallel \scriptstyle S \\
 H_c^*(F) \longleftarrow H_{cv}^*(E) & & R\pi_{F,!} \mathbb{Z}_F \longleftarrow R\pi_{B,*} R\pi_! \mathbb{Z}_E \\
 \downarrow \sim & & \downarrow \sim \\
 H^{*-r}(B) & & R\pi_{B,*} \mathbb{Z}_B[-r]
 \end{array}$$

This page works on the details of the last exercise. If you did that exercise or don't care the details, then skip this page.  
 Notice that we ignore the difference between the complex and cohomology, which is just for the convenience of presentation.

**Lemma.**  $R\pi_! \mathbb{Z}_E \cong \mathbb{Z}_B[-r]$ . As a result,  $H_{cv}^i(E) \cong H^{i-r}(B)$ .

**Proof.**

$$\begin{aligned} R\pi_! \mathbb{Z}_E &= R\pi_! \pi^* \mathbb{Z}_B \\ &\cong R\pi_! \pi^! \mathbb{Z}_B[-r] \\ &\xrightarrow{\sim} \mathbb{Z}_B[-r] \end{aligned}$$

expand

Verdier duality,  $\pi$  is a v.b. adjunction, iso comes from

$$H_*(\mathbb{R}^r; \mathbb{Z}) \cong \mathbb{Z} \text{ (check locally)}$$

strictly speaking,  $H_{cv}^i(E) = \mathcal{H}^i(\pi_{B,*} R\pi_! \mathbb{Q}_E)$ , but we're lazy to write  $\mathcal{H}$

$$\begin{aligned} H_c^i(F) &\stackrel{\text{trick!}}{=} (R\pi_! \mathbb{Z}_E)_P \\ &= l_P^* R\pi_! \mathbb{Z}_E \\ &= \pi_{B,*} l_{P,*} l_P^* R\pi_! \mathbb{Z}_E \longleftarrow \pi_{B,*} R\pi_! \mathbb{Z}_E = H_{cv}^i(E) \end{aligned}$$

Compare with the first row:

$$\begin{aligned} R\pi_{F,*} \beta_{F,!} \mathbb{Z}_F &= R\pi_{E,*} l_{F,*} \beta_{F,!} l_F^* \mathbb{Z}_E \\ &\stackrel{bc}{=} R\pi_{E,*} l_{F,*} l_F^* \beta_{E,!} \mathbb{Z}_E \longleftarrow R\pi_{E,*} \beta_{E,!} \mathbb{Z}_E \end{aligned}$$

Q: How to show that  $H^0(B) \longrightarrow H_c^r(F) \quad 1 \mapsto \text{generator?}$

A:

$$\begin{aligned} H^{i-r}(B) = R\pi_{B,*} \mathbb{Z}_B[-r] &\longrightarrow R\pi_{B,*} l_{P,*} l_P^* \mathbb{Z}_B[-r] \\ &= l_P^* \mathbb{Z}_B[-r] = \mathbb{Z}_{\{P\}}[-r] \\ &\xrightarrow{1 \mapsto \text{generator}} \\ &\cong l_P^* R\pi_! \mathbb{Z}_E \\ &\stackrel{bc}{\cong} R\pi_{F,!} l_F^* \mathbb{Z}_E \\ &= R\pi_{F,!} \mathbb{Z}_F = H_c^i(F) \end{aligned}$$

## Euler class of v.b.

People are lazy to write all contravariant functors induced by  $s$  as  $s^*$ . It may be not the pullback in the 6-functor formalism. These may cause confusion, and I hope it is fine for you.

Ex construct

$$\begin{array}{ccc} s^*: H_{cv}^*(E) & \longrightarrow & H^*(B) \\ \parallel & & \parallel \\ R\pi_{B,*} R\pi_! \mathbb{Z}_E & & R\pi_{B,*} \mathbb{Z}_B \end{array} \quad \Phi \longmapsto eu_E$$

After this exercise, we get euler class  $eu_E \in H^r(B)$ .

⊗ for Ex:  $\pi \circ s = Id$ , so

$$R\pi_{B,*} R\pi_! \mathbb{Z}_E \longrightarrow R\pi_{B,*} (R\pi_! s_*) s^* \mathbb{Z}_E = R\pi_{B,*} \mathbb{Z}_B.$$

□

Ex. Find a way to define  $eu_E$  without using  $\Phi$ , i.e. construct

$$\begin{array}{ccc} H^{*-r}(B) & \longrightarrow & H^*(B) \\ \parallel & & \parallel \\ R\pi_{B,*} \mathbb{Z}_B[-r] & & R\pi_{B,*} \mathbb{Z}_B \end{array} \quad 1 \longmapsto eu_E$$

[ Hint. Induced by  $\mathbb{Z}_B[-r] \cong R\pi_! \mathbb{Z}_E \xrightarrow{\quad} (R\pi_! s_*) s^* \mathbb{Z}_E \cong \mathbb{Z}_B$  ]

in fact, use  $\mathbb{Z}_E \longrightarrow s_* \mathbb{Z}_B$

## Relation with tubular nbhd

Let  $j: E \setminus B \hookrightarrow E$ ,  $T$ : tubular nbhd of  $B$  in  $E$ ,  
 $\uparrow$   
 $s(B)$ , if you prefer rigorous notation

by applying  $R\pi_{B,*} R\pi_!$  to

$$0 \longrightarrow j_! j^! \mathbb{Z}_E \longrightarrow \mathbb{Z}_E \longrightarrow s_* s^* \mathbb{Z}_E \longrightarrow 0$$

we get LES:

$$\begin{array}{ccccccc} R\pi_{B,*} R\pi_{|E \setminus B}| \mathbb{Z}_{E \setminus B} & \longrightarrow & H_{cv}^*(E) & \xrightarrow{\quad} & H^*(B) & \xrightarrow{+1} & \\ \parallel & & \parallel & \nearrow eu_E \wedge & \parallel & & \\ H^{*-r}(\partial T) & \longrightarrow & H^{*-r}(T) & \longrightarrow & H^*(T) & \xrightarrow{+1} & \\ \parallel & & \parallel & & \parallel & & \\ H^{*-r}(\partial T) & \longrightarrow & H^{*-r}(T) & \longrightarrow & H^*(T) & \xrightarrow{+1} & \end{array}$$



## Euler class of sphere bundle

Ex: Use the similar method, construct the Gysin sequence.

$$H^n(B) \xrightarrow{\pi^*} H^n(E) \xrightarrow{\pi_*} H^{n-k}(B) \xrightarrow[eu_\pi]{+1} H^{n-k+1}(B)$$

$$\begin{array}{ccc} S^k & \xrightarrow{\iota_k} & E \\ & \downarrow \pi \text{ oriented} & \\ & B & \end{array}$$

Hint: Apply the functor  $R\pi_{B,*}$  to

$$\begin{array}{ccccc} R^0 \pi_* \mathbb{Q}_E & \longrightarrow & R\pi_* \mathbb{Q}_E & \longrightarrow & R^k \pi_* \mathbb{Q}_E[-k] \xrightarrow{+1} \\ \parallel & & & & \parallel \\ \mathbb{Q}_B & & & & \mathbb{Q}_B[-k] \end{array}$$

Therefore, Euler class roughly describes the connecting map

$$\mathbb{Q}_B[-k] \longrightarrow \mathbb{Q}_B[1] \text{ after applying } R\pi_{B,*}$$

It works as an obstruction for "the triangle to be exact".

⚠  $Rf \neq \bigoplus R^i f[-i]$ . Instead,

$$\emptyset \subsetneq R^0 f \subsetneq \dots \subsetneq R^1 f[-1] \subsetneq \dots \subsetneq R^n f[-n] \subsetneq Rf.$$

It's constructed by truncations.

## Hard Exercise

1. When the  $S^k$ -bundle  $\pi: E \rightarrow B$  has a section, show that  $ev_E = 0$ . Do we have

$$R\pi_* \pi^* \mathbb{Q}_B \cong \mathbb{Q}_B \oplus \mathbb{Q}_B[-k] ?$$

I think so.

2. For a  $rk \leq r$  v.b.  $\pi: E \rightarrow B$  and the crspd  $S^{r-1}$ -bundle  $\tilde{\pi}: \tilde{E} \rightarrow B$ , show that they define the same Euler class. How are their Gysin sequences related?

3. Discuss the maps

$$\begin{array}{ccccc} \text{Vect}_B^{rk, r} & \longrightarrow & \{S^{r-1}\text{-bundle over } B\} & \longrightarrow & H^r(B; \mathbb{Z}) \\ E & \longmapsto & \tilde{E} & \longmapsto & ev_{\tilde{E}} \end{array}$$

Are they surj? inj?

Here,  $E \cong E'$  iff  $\exists$

$$\begin{array}{ccc} E & \xrightarrow{\exists \text{ linear fiberwise}} & E' \\ \pi \searrow & & \swarrow \pi' \\ & B & \end{array}$$

$$\tilde{E} \cong \tilde{E}' \text{ iff } \exists \begin{array}{ccc} E & \xrightarrow{\exists \text{ homeo fiberwise}} & E' \\ \pi \searrow & & \swarrow \pi' \\ & B & \end{array}$$

4.

[https://en.wikipedia.org/wiki/Chern\\_class#Via\\_an\\_Euler\\_class](https://en.wikipedia.org/wiki/Chern_class#Via_an_Euler_class)

Can we directly define Chern class by 6-fctors?

How to define other characteristic classes by 6-fctors?

## Explanation

### Exactness & derived

$j_!$  is exact  
 $i^*, j^*$  are exact  
 $i_*$  is exact

by checking on stalks  
 in the category  $\mathcal{T}op$   
 when  $Z \subset X$  is (strongly) loc. contractable.

$j_*$  is not exact  $\rightsquigarrow Rj_*$   
 $i^!$  is already derived.

Rmk: strongly loc. contractable:  $\forall p \in X, \exists$  a nbhd basis  $\{U_n\}_n$  of  $p$   
 s.t.  $U_n \cap Z$  is contractable  
 loc. contractable:  $\forall p \in X, \exists$  a nbhd basis  $\{U_n\}_n$  of  $p$   
 s.t.  $U_n \cap Z \subset U_n$  is contractable

E.g.  $\{ \text{strongly loc. contractable} \} \subsetneq \{ \text{loc. contractable} \} \not\subseteq \mathcal{T}op$   
 CW-cplx, topo mflds Cantor set  
 & algebraic varieties (Check?)

See the answer in

<https://math.stackexchange.com/questions/1082601/anr-is-locally-contractible>  
 for the subtlety of these two definitions.

I don't care. In both cases, the local cohomology vanishes in higher degree, and that's what I want.

For the non-exact functors, there maybe some problems in the composition of derived functors.

<https://mathoverflow.net/questions/108734/theorem-on-composition-of-derived-functors-question-about-proof>

<https://mathoverflow.net/questions/435310/what-can-be-said-about-the-derived-functor-of-a-composition-between-unbounded-de>

E.g. we need to check if  $R\pi_{x,*} \circ Rj_* = R\pi_{u,*}$ .  
 Luckily, in the open-closed formalism, we won't meet these problems.

Prop1. Let  $e \xrightleftharpoons[G]{F} e'$ , assume  $F$  is exact. Then

①  $G$  preserves injective sheaves;

②  $RG(f) \circ RG(g) = RG(f \circ g)$

Proof. ①: by universal property.

②: by adjunction

Prop 2. Let  $\mathcal{C} \xrightleftharpoons[G]{F} \mathcal{C}' \xrightleftharpoons[G']{F'} \mathcal{C}''$ . Suppose  $F$  or  $F'$  is exact, then

$$RG \circ RG'(f) = (R(G \circ G'))(f)$$

Proof. By adjunction & Grothendieck-Serre sequence.  $(LF' \circ LF = L(F' \circ F))$   
 When  $F'$  is exact, can use Prop 1  $\oplus$ .

Cor.  $R\pi_{x,*} \circ Rj_* = R\pi_{u,*}$ .

$Rf_*$  &  $Rf_!$  are nice in general.

Reason:  $f_!$  sends skyscraper sheaf to skyscraper sheaf, and in general preserve injective sheaves. (need double check)

## Local properties

1. They can be checked locally on the target.

$f^*$ : composition  
 $f^!$ : composition +  $j^* = j^!$   
 $Rf_!$ : proper bc  
 $Rf_*$ : adjunction of proper bc

2. Stalk:

$f^*$ : composition  
 $f^!$ : for  $i^!$ , use triangles  $\leadsto R\Gamma(X, \mathcal{U}; \mathcal{F})$   
 for  $j^!$ ,  $j^! = j^*$   
 for  $\pi^!$ ,  $\pi^! \sim \mathcal{O}_r[n]$   
 $Rf_!$ : proper bc  $\leadsto$  local (proper) cohomology  
 $Rf_*$ : local cohomology by definition

$$\begin{array}{ccc}
 Y_p & \xleftarrow{l_{p,Y}} & Y \text{---} \mathcal{G} \\
 f|_{Y_p} \downarrow & & \downarrow f \\
 \{p\} & \xrightarrow{l_p} & X \text{---} \mathcal{F}
 \end{array}$$

proper bc to compute stalk of  $Rf_!$