

Eine Woche, ein Beispiel

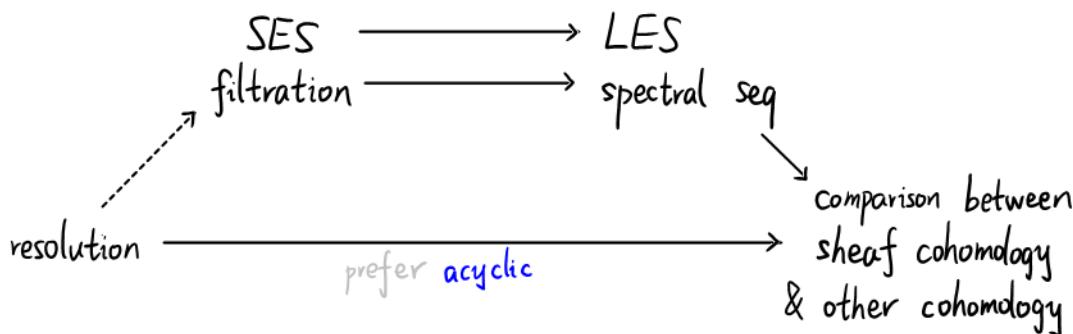
1.28 conormal bundle

Ref. from [23.11.19]

slogan:

SES induces LES,  
filtration induces spectral sequence.

To expand a little bit,



Even though "filtration  $\Rightarrow$  spectral seq" is the most general statement, people start with " $\text{SES} \Rightarrow \text{LES}$ " and "acyclic resolution  $\Rightarrow$  other coh  $\approx$  hyper coh".  
Let us leave spectral seq in other people's notes.

1. open-closed formalism
2. open cover
3. filtrations from chain complex
4. filtration by  $H^i(\mathcal{F})$
5. filtration by  $\mathcal{F}$
6. Hodge related filtration

Methods to construct SES:  $\left\{ \begin{array}{l} \text{check by stalks} \\ \text{filtration by } H^i(F) \\ \text{filtration by } F^i \end{array} \right.$

method	spectral seq	LES	cohomology/resolution
check by stalks	... for stratifications	relative coh seq	simplicial/cellular
	Čech-to-derived functor	MV	Čech
	coefficient		—
filtration by $H^i(F)$	Grothendieck		
	Leray-Serre	Cysin	Euler class Hodge-Tate
filtration by $F^i$ need resolution to get "another" complex	Hodge-de Rham		de Rham, Hodge-de Rham Dolbeault $H^p(X, \Omega^q) = H^{p+q}(X)$
	Frölicher		$H^{p,q}(X) \Rightarrow H^{p+q}(X)$ "composition" singular
spectral sequences which	Adams		for stable homotopy gp
	Atiyah-Hirzebruch		for top K-theory
I don't know	Bar		for group
	Bockstein		for group homology
	Cartan-Leray		
	Eilenberg-Moore		
	Green		for Koszul cohomology
	:		:

For more spectral sequences, see:

[https://en.wikipedia.org/wiki/Spectral\\_sequence](https://en.wikipedia.org/wiki/Spectral_sequence)

<https://github.com/CubicBear/SpectralSequences/blob/main/SpectralSequences.pdf>

# 1. open-closed formalism

|| related: comparison of  $j_!$  &  $j_*$   
one-point compactification.

Observe the following pictures:

$$\begin{array}{ccccc}
 Z & \xrightarrow{i} & X & \xleftarrow{j} & U \\
 & \xleftarrow{i^*} & & \xleftarrow{j_!} & \\
 D(Z) & \xrightarrow[i_* = i_!]{i^!} & D(X) & \xrightarrow[j^* = j_!]{j^!} & D(U) \\
 & \xleftarrow{i^!} & & \xleftarrow{Rj_*} &
 \end{array}$$

Black box:

0. We assume some nice conditions.

e.g. in the category  $\text{Haus}^{\text{loc. cpt}}$ , and  $Z \subset X$  is loc. contractible.

Under these conditions,

1.  $i_* = i_!$ ,  $j^* = j_!$
2.  $i_!, i^!, j^*, i_*$  are exact.

Ex. 1. Shows that

$$\underline{i^* i_*} = \underline{i^! i_*} = \text{Id}_{D(Z)} \quad \underline{j^* j_!} = \underline{j^* Rj_*} = \text{Id}_{D(U)}$$

$$\underline{i^* j_!} = 0, \quad \underline{j^* i_*} = 0, \quad \underline{i^! Rj_*} = 0$$

—, base change

~~~~: check stalkwise.

2. (for category fans)

$i_*, j_*, j_!$  are fully faithful, and

$i_*, i^!, j^*, Rj_*$  preserve injectives.

3. One has SES

$$0 \longrightarrow j_! j^! F \longrightarrow F \longrightarrow i_* i^* F \longrightarrow 0 \quad (1)$$

Ex for (1).

1. Apply the  $R\pi_{X,*}$  to (1), take  $\mathcal{F} = \underline{\mathbb{Q}}_X$ , what do we get?

In general, what do we get when applying  $R\pi_{X,*}$  &  $R\pi_{X,!}$ ?  
Discuss 2 spectral cases  $\mathcal{F} = \underline{\mathbb{Q}}_X$   $D_X$   $D_{X,!} = \pi_X^! \underline{\mathbb{Q}}_{\mathbb{R}^n} = D_X(\underline{\mathbb{Q}}_X)$

2. Derive from (1) the SES

$$0 \longrightarrow j_* \mathcal{F} \longrightarrow Rj_* \mathcal{F} \longrightarrow i_* i^* Rj_* \mathcal{F} \longrightarrow 0$$

which measures the difference between  $j_* \mathcal{F}$  &  $j^* \mathcal{F}$ .

3. Shows that

$$H_c(X) \cong H(\bar{X}, \{\infty\}; \mathbb{Z})$$

for one pt compactification  $i: X \hookrightarrow \bar{X}$ .

Try to compute  $H_c(\mathbb{R}^n)$  in this way.

It seems that we get only half of the results.

### Verdier dual

Def. The Verdier dual / dualizing functor is defined as

$$ID_X : D^b(X; \mathbb{Q}) \longrightarrow D^b(X; \mathbb{Q}) \quad ID_X \mathcal{F}^\cdot := \underline{\text{Hom}}_{D^b(X; \mathbb{Q})}(\mathcal{F}^\cdot, \pi_X^! \underline{\mathbb{Q}}_{\mathbb{P}^1})$$

We know that

$$ID_X \underline{\mathbb{Q}}_X = \pi_X^! \underline{\mathbb{Q}}_{\mathbb{P}^1}$$

$$ID_X(\mathcal{F}[n]) = (ID_X \mathcal{F}^\cdot)[-n]$$

$$\mathcal{F}^\cdot \longrightarrow \mathcal{G}^\cdot \longrightarrow \mathcal{H}^\cdot \xrightarrow{+1} \rightsquigarrow ID \mathcal{H}^\cdot \longrightarrow ID \mathcal{G}^\cdot \longrightarrow ID \mathcal{F}^\cdot \xrightarrow{+1}$$

$$f^! ID_X = ID_Y f^*$$

$$Rf_* ID_Y = ID_X Rf_!$$

$$f: Y \longrightarrow X$$

When  $\mathcal{F}^\cdot \in D^b(X; \mathbb{Q})$  is constructable, then

$$ID_X^2 \mathcal{F}^\cdot \cong \mathcal{F}^\cdot$$

Therefore, in the constructable setting,

$$f^* ID_X = ID_Y f^*$$

$$Rf_* ID_Y = ID_X Rf_*$$

For exact statements about  $ID_X$ , see [MS21, Cor 2.11] [IHPS, Thm 5.3.9]

Ex. Derive from (1) the triangle

$$i_! i^* \mathcal{F}^\cdot \longrightarrow \mathcal{F}^\cdot \longrightarrow Rj_* j^* \mathcal{F}^\cdot \xrightarrow{+1} \tag{2}$$

for  $\mathcal{F}^\cdot \in D^b(X; \mathbb{Q})$  constructable.

Ex for (2). Do the same arguments in "Ex for (1)".

E.g. For a finite graph (as a topo space)  $X$ ,

$$\begin{array}{ccc} \vdots & \text{blue graph} & \vdots \\ \text{sk}_0 X & \xleftarrow{i} & X & \xleftarrow{j} & X - \text{sk}_0 X & \text{1-cells} \end{array}$$

$$0 \longrightarrow j_! j^* \underline{\mathbb{Q}}_X \longrightarrow \underline{\mathbb{Q}}_X \longrightarrow i_* i^* \underline{\mathbb{Q}}_X \longrightarrow 0$$

$$0 \longrightarrow j_! \underline{\mathbb{Q}}_{X - \text{sk}_0 X} \longrightarrow \underline{\mathbb{Q}}_X \longrightarrow i_! \underline{\mathbb{Q}}_{\text{sk}_0 X} \longrightarrow 0$$

Take  $R\pi_{X,!}$ :

$$\begin{array}{c} \xrightarrow{\quad H_c(X - \text{sk}_0 X) \xrightarrow{= \oplus \mathbb{Q}} \quad} \\ \xrightarrow{\quad H_c(X) \quad} \\ \xrightarrow{\quad H_c(\text{sk}_0 X) \xrightarrow{= 0} \quad} \end{array}$$

$$0 \longrightarrow H_c^0(X - \text{sk}_0 X) \xrightarrow{= 0} H_c^0(X) \longrightarrow H_c^0(\text{sk}_0 X) \xrightarrow{= \oplus \mathbb{Q}}$$

This calculates the sheaf cohomology as simplicial cohomology.

E.x. Shows that

$$H_c^i(\mathbb{R}) = \begin{cases} \mathbb{Q} & i=1 \\ 0 & \text{otherwise} \end{cases}$$

in a similar way.

Generalizing this argument, one can relate sheaf cohomology with simplicial / cellular cohomology, using the following filtration:

$$0 \subset \text{sk}^0 X \subset \text{sk}^1 X \subset \cdots \subset \text{sk}^n X = X$$

Ex. derive the Wang LES for the cpt supp version over  $S^1$

## 2. open cover

Ex. For an open cover  $X = U_1 \cap U_2$ , deduce the SES

$$0 \leftarrow \underline{\mathbb{Q}}_X \xleftarrow{\quad} j_! \underline{\mathbb{Q}}_{U_1} \oplus j_! \underline{\mathbb{Q}}_{U_2} \xleftarrow{\quad} j_! \underline{\mathbb{Q}}_{U_1 \cap U_2} \xleftarrow{\quad} 0$$

$$\underline{\mathbb{Q}}_X \longrightarrow Rj_* \underline{\mathbb{Q}}_{U_1} \oplus Rj_* \underline{\mathbb{Q}}_{U_2} \longrightarrow Rj_* \underline{\mathbb{Q}}_{U_1 \cap U_2} \xrightarrow{+1} 0 \quad (3)$$

▽ We omit the derived symbol and some subscripts in this section.  $U_{12} = U_1 \cap U_2$

(3) works for general sheaf

and, induce from (3) the MV sequence:

$$\begin{array}{ccccccc} & \xleftarrow{+1} & H_c^k(X) & \xleftarrow{\quad} & H_c^k(U_1) \oplus H_c^k(U_2) & \xleftarrow{\quad} & H_c^k(U_1 \cap U_2) \\ & & H^k(X) & \longrightarrow & H^k(U_1) \oplus H^k(U_2) & \longrightarrow & H^k(U_1 \cap U_2) \xrightarrow{+1} \end{array}$$

Hint: Apply  $R\pi_{X,!}$  &  $R\pi_{X,*}$ , see [StackProject, 01E9]

Ex. Derived the Wang LES. over  $S^1$

Ex. For an open cover  $X = \bigcup_{i \in \Lambda} U_i$ ,  $\Lambda$  finite, deduce the exact seq

$$0 \leftarrow \underline{\mathbb{Q}}_X \leftarrow \bigoplus_i j_! \underline{\mathbb{Q}}_{U_i} \leftarrow \bigoplus_{i < j} j_! \underline{\mathbb{Q}}_{U_i \cap U_j} \leftarrow \cdots j_! \underline{\mathbb{Q}}_{\bigcap U_i} \leftarrow 0$$

and t-exact seq

$$0 \longrightarrow \underline{\mathbb{Q}}_X \longrightarrow \bigoplus_i Rj_* \underline{\mathbb{Q}}_{U_i} \longrightarrow \bigoplus_{i < j} Rj_* \underline{\mathbb{Q}}_{U_i \cap U_j} \longrightarrow \cdots Rj_* \underline{\mathbb{Q}}_{\bigcap U_i} \longrightarrow 0$$

When  $\{U_i\}_{i \in \Lambda}$  is a good cover,  $H^i(U_{i_1, \dots, i_k}) = H^0(U_{i_1, \dots, i_k})$ ,  
 $\uparrow$  acyclic in AG

one can compute  $H^i(X)$  by applying  $R\pi_{X,*}$ :

$$\begin{array}{ccccccc} 0 \longrightarrow & \bigoplus_i \Gamma(U_i) & \xrightarrow{d^1} & \bigoplus_{i < j} \Gamma(U_i \cap U_j) & \xrightarrow{d^2} & \cdots & \Gamma(\bigcap U_i) \longrightarrow 0 \\ & H^0(X) & & H^1(X) & & \cdots & H^{|\Lambda|-1}(X) \\ & & & & \downarrow \text{Ker/Im} & & \end{array}$$

Rmk. When  $X$  is paracompact & Hausdorff, "limited" Čech = sheaf  
 $\uparrow$  e.g. loc cpt Haus + second-countable, or CW cplx

compare the first step:

$$F \longrightarrow \bigoplus_i Rj_* F|_{U_i} \qquad F \longrightarrow \bigoplus_{x \in X} F_x$$

If you haven't seen the acyclic resolution before, the following example may provide some intuition.

#  $\Delta = 3$  case:

$$\begin{array}{ccccccc}
 & & \circ & & \circ & & \\
 & & \searrow & & \swarrow & & \\
 & & F_0 & & & & \\
 & \nearrow & & \searrow & & & \\
 0 \rightarrow & Q_X \rightarrow & \bigoplus_i Rj_* \mathbb{Q}_{U_i} & \xrightarrow{d'} & \bigoplus_i Rj_* \mathbb{Q}_{U_i \cap U_j} & \xrightarrow{d''} & Rj_* \mathbb{Q}_{\cap U_i} \rightarrow 0 \\
 & & \downarrow & & \downarrow & & \\
 & & F_1 & & F_2 & & \\
 & & \circ & & \circ & & \\
 & & \searrow & & \swarrow & & \\
 & & & & & &
 \end{array}$$

$$F_2 = Rj_* \mathbb{Q}_{\cap U_i} \Rightarrow H^*(F_2) = \ker d^3$$

$$\begin{array}{ccccc}
 \underbrace{H^*(F_1)}_{0 \rightarrow H^0(F_1) \rightarrow \bigoplus_{i<j} \Gamma(U_i \cap U_j) \xrightarrow{d''}} & \longrightarrow & 0 & \longrightarrow & H^*(F_2) \xrightarrow{+1} \\
 & & & & \curvearrowright H^0(F_2) \\
 & & & & 
 \end{array}$$

$$\Rightarrow H^i(F_1) = \begin{cases} \ker d^3 / \text{Im } d^2, & i=1 \\ \ker d^2, & i=0 \\ 0, & \text{otherwise} \end{cases}$$

$$\begin{array}{ccccc}
 \underbrace{H^*(F_0)}_{0 \rightarrow H^0(F_0) \rightarrow \bigoplus_i \Gamma(U_i) \xrightarrow{d'}} & \longrightarrow & 0 & \longrightarrow & H^*(F_1) \xrightarrow{+1} \\
 & & & & \curvearrowright H^1(F_0) \\
 & & & & 
 \end{array}$$

$$\Rightarrow H^i(X) = H^i(F_0) = \begin{cases} \ker d^3 / \text{Im } d^2 & i=2 \\ \ker d^2 / \text{Im } d^1 & i=1 \\ \ker d^1 & i=0 \\ 0, & \text{otherwise} \end{cases}$$

Rmk. When  $\{U_i\}_{i \in \Delta}$  is not a good cover,  
one needs Čech-to-derived functor spectral seq to compute  $H^*(X)$ .

Rmk. stratification & open cover are two main tools to extract topological information.  
 They appear with different names in different fields.  
 Once you realize them, you can apply the six-functor machine to analyze structures.

stratification with extra properties

|   |                        |
|---|------------------------|
| { | CW cplx                |
|   | triangulization        |
|   | dessin d'enfant        |
|   | affine paving          |
|   | Whitney stratification |
|   | :                      |

Q. How to construct stratifications?

A. For me, there are two efficient methods:

|   |                    |
|---|--------------------|
| { | orbit of gp action |
|   | Morse theory       |

That's why some geometrical problems are finally reduced to combinatorical / analytic problems.  
 Other fields come to geometry by providing stratifications.

In fact, there is only one method:

find a fct  $f: X \rightarrow Y$ , and get stratification of  $X$  from  $Y$ .  
 get better stratification by analyzing  $f$

|      |                        |                                                                 |
|------|------------------------|-----------------------------------------------------------------|
| E.g. | 1. Morse theory        | $f: X \rightarrow \mathbb{R}$                                   |
|      | 2. tessellation        | $f: H \rightarrow H/\Gamma$                                     |
|      | 3. semi-continuous fct | $f: X \rightarrow \mathbb{N}_{\geq 0}$ e.g. $f(p) = \dim T_p X$ |
|      | 4. my thesis           | $f: Gr(X) \rightarrow Gr(S) \times Gr(X/S)$                     |
|      | 5. orbit of gp action  | $f: X \rightarrow X/G$                                          |

### 3. filtrations from chain complex [Stack Project, 0118]

Lots of filtrations are obtained just from the naive complex.

Consider a chain complex  $C$ :

$$\dots \xrightarrow{d^{-2}} C^{-2} \xrightarrow{d^{-1}} C^{-1} \xrightarrow{d^0} C^0 \xrightarrow{d^1} C^1 \xrightarrow{d^2} C^2 \xrightarrow{d^3} \dots$$

One can make a "stupid" truncation

$$\begin{array}{ccccccccc} \dots & \longrightarrow & 0 & \longrightarrow & 0 & \longrightarrow & C^0 & \xrightarrow{d^1} & C^1 \xrightarrow{d^2} C^2 \xrightarrow{d^3} \dots \\ & & \downarrow & & \downarrow & & \downarrow & & \downarrow \\ \dots & \xrightarrow{d^{-2}} & C^{-2} & \xrightarrow{d^{-1}} & C^{-1} & \xrightarrow{d^0} & C^0 & \xrightarrow{d^1} & C^1 \xrightarrow{d^2} C^2 \xrightarrow{d^3} \dots \\ & & \downarrow & & \downarrow & & \downarrow & & \downarrow \\ \dots & \xrightarrow{d^{-2}} & C^{-2} & \xrightarrow{d^{-1}} & C^{-1} & \longrightarrow & 0 & \longrightarrow & 0 \longrightarrow \dots \end{array}$$

which is denoted by

$$0 \longrightarrow \sigma_{\geq 0} C \longrightarrow C \longrightarrow \sigma_{\leq -1} C \longrightarrow 0$$

One can also make a canonical truncation

$$\begin{array}{ccccccccc} \dots & \xrightarrow{d^{-2}} & C^{-2} & \xrightarrow{d^{-1}} & C^{-1} & \xrightarrow{d^0} & \ker d' & \longrightarrow & 0 \longrightarrow 0 \longrightarrow \dots \\ & & \downarrow & & \downarrow & & \downarrow & & \downarrow \\ \dots & \xrightarrow{d^{-2}} & C^{-2} & \xrightarrow{d^{-1}} & C^{-1} & \xrightarrow{d^0} & C^0 & \xrightarrow{d^1} & C^1 \xrightarrow{d^2} C^2 \xrightarrow{d^3} \dots \\ & & \downarrow & & \downarrow & & \downarrow & & \downarrow \\ \dots & \longrightarrow & 0 & \longrightarrow & 0 & \longrightarrow & \text{coker } d^0 & \xrightarrow{d^1} & C^1 \xrightarrow{d^2} C^2 \xrightarrow{d^3} \dots \end{array}$$

which is denoted by

$$0 \longrightarrow \tau_{\leq 0} C \longrightarrow C \longrightarrow \tau_{\geq 1} C \longrightarrow 0$$

Using these truncations, one can easily construct filtrations:

$$0 \subset \cdots \subset \sigma_{\geq 1} C \overset{C^{[-1]}}{\subset} \sigma_{\geq 0} C \overset{C^0}{\subset} \sigma_{\geq -1} C \subset \cdots \subset C$$

$$0 \subset \cdots \subset \tau_{\leq -1} C \overset{H^0(C)}{\subset} \tau_{\leq 0} C \overset{H^0(C)[1]}{\subset} \tau_{\leq 1} C \subset \cdots \subset C$$

Rmk. 1. These two filtrations have opposite directions!

(a striking feature for me)

2. The "stupid" truncation extracts pieces of the chain cplx, while the canonical truncation extracts cohomology. ( $\text{Ker}/\text{Im}$ )  
Therefore, only the canonical truncation can be defined on the derived category.

This information is culmulated in the standard/natural t-structure  $(D_{\leq 0}, D_{\geq 0})$ .

One has adjoint factors:

$$\begin{array}{ccccc} & & l_{\leq 0} & & \\ & \swarrow \perp \curvearrowright & & \curvearrowright \perp \searrow & \\ D_{\leq 0} & & D & & D_{\geq 1} \\ & \searrow \tau_{\leq 0} & & l_{\geq 0} & \swarrow \end{array}$$

The following notations are from: <https://ncatlab.org/nlab/show/t-structure>

$D_{\leq 0}$ : t-co-connective objects  
 $D_{\geq 0}$ : t-connective objects  
 $\tau_{\geq 0}$ : connective cover

Let's apply these filtrations!

#### 4. filtration by $H^*(F)$

Ex. Suppose that  $\pi: E \rightarrow B$  is an oriented  $S^k$ -bundle.

Analyze  $R\pi_* \mathbb{Q}_E$ , and apply  $R\pi_{B,*}$  to get the Gysin sequence.

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

Q. Why does  $\pi_*: D^b(E) \rightarrow D^b(B)$  takes injective objects to  $\pi_{B,*}$ -acyclic objects?

Rmk. 1. Here we can't use the "stupid" truncation,

because  $R\pi_* \mathbb{Q}_E$  lies in the derived category.

2. You can generalize it to fiber bundle, then

you will get the Leray-Serre spectral sequence.

Think how the following conditions simplify the final results.

①  $\pi$  is oriented  $S^k$ -bundle

②  $B$  is simply-connected

③ (Leray-Hirsch)  $H^*(E; \mathbb{Q}) \rightarrow H^*(F; \mathbb{Q})$  is surjection

④  $\pi_*(B)$  acts on  $H^*(F)$  trivially.

3. This is also a special case of Grothendieck-Serre spectral sequence.

## 5. filtration by $\mathcal{F}$

For a single sheaf  $\mathcal{F}$ , we have no way to produce filtrations.

Since we only care about  $H^i(\mathcal{F})$ , we may replace  $\mathcal{F}$  by another complex  $C^\bullet$ , which is usually achieved by resolution:

$$0 \longrightarrow \mathcal{F} \xrightarrow{\varepsilon} C^0 \xrightarrow{d^0} C^1 \xrightarrow{d^1} C^2 \xrightarrow{d^2} \cdots \quad \text{exact}$$

i.e.

$$\begin{array}{ccccccc} 0 & \longrightarrow & \mathcal{F} & \longrightarrow & 0 & \longrightarrow & 0 \longrightarrow \cdots \\ & & \downarrow \varepsilon & & \downarrow & & \downarrow \\ 0 & \longrightarrow & C^0 & \xrightarrow{d^0} & C^1 & \xrightarrow{d^1} & C^2 \xrightarrow{d^2} \cdots \end{array} \quad \text{iso in } \mathcal{D}(X)$$

Then, one can use "stupid" truncation to get filtrations, and finally spectral sequences.  
(The canonical truncation won't give you anything new)

E.p. When  $C^\bullet$  is  $\pi_*$ -acyclic, the spectral seq deg. and  
 $H^i(X; \mathcal{F}) \cong H^i(C^\bullet)$ .

E.g. The spectral seqs in Section 1,2 are special cases.

## Coefficient spectral seq

E.g. For  $r \in \mathbb{Z}_{>0}$ , consider the SES

$$0 \longrightarrow \underline{\mathbb{Z}} \xrightarrow{x^r} \underline{\mathbb{Z}} \longrightarrow \underline{\mathbb{Z}/r\mathbb{Z}} \longrightarrow 0$$

which induces the iso

$$\underline{\mathbb{Z}/r\mathbb{Z}} \cong [\rightarrow \underline{\mathbb{Z}} \xrightarrow{x^r} \underline{\mathbb{Z}} \longrightarrow]$$

the triangle

$$\underline{\mathbb{Z}} \longrightarrow \underline{\mathbb{Z}/r\mathbb{Z}} \longrightarrow \underline{\mathbb{Z}}[1] \xrightarrow{+1}$$

and the LES

$$H^k(X; \mathbb{Z}) \longrightarrow H^k(X, \underline{\mathbb{Z}/r\mathbb{Z}}) \longrightarrow H^{k+1}(X, \underline{\mathbb{Z}}) \xrightarrow{+1}$$

Ex. Compute  $H^k(\mathbb{R}\mathbb{P}^2; \underline{\mathbb{Z}/8\mathbb{Z}})$  in this way.

$$A: H^k(\mathbb{R}\mathbb{P}^2; \underline{\mathbb{Z}/8\mathbb{Z}}) = \begin{cases} \underline{\mathbb{Z}/8\mathbb{Z}}, & k=0 \\ \underline{\mathbb{Z}/2\mathbb{Z}}, & k=1,2 \\ 0, & \text{otherwise.} \end{cases}$$

Rmk. In general, one can get coefficient spectral seq [FF16, 20.5.B, p318] through the coefficient seq.  $G$  abelian

$$\dots \xrightarrow{\partial_2} \underline{G}_1 \xrightarrow{\partial_1} \underline{G}_0 \xrightarrow{\epsilon} \underline{G} \longrightarrow 0$$

Q. Can we recover the inflation - restriction seq in this way?

$$0 \longrightarrow H^*(G/H, M^H) \xrightarrow{\text{Inf}} H^*(G, M) \xrightarrow{\text{Res}} H^*(H, M)$$

A: I think no. We haven't introduce  ${}^L\otimes$  &  $R\text{Hom}$ .

## Singular cohomology

We present a defective proof in [Voo2, Theorem 4.47].

The bug has been discussed in the stack exchange:

<https://math.stackexchange.com/questions/1794725/detail-in-the-proof-that-sheaf-cohomology-singular-cohomology>

|                 |                     |                             |                                          |
|-----------------|---------------------|-----------------------------|------------------------------------------|
| [Stackexchange] | $\mathcal{S}^k$     | $\widetilde{\mathcal{S}}^k$ | $\mathcal{S}^k(X)_\circ$                 |
| [Voo2]          | $C_{\text{sing}}^k$ | $C_{\text{sing}}^k$         | $C_{\text{sing}}^k(U, \mathbb{Z})_\circ$ |

$X \in \mathbf{Top}$ .

Def The presheaf  $\mathcal{S}^k \in \text{Psh}(X)$  is defined as

$$\begin{aligned}\mathcal{S}^k(U) &= \text{singular } k\text{-cochains on } U \\ &= \text{Hom}_{\text{Abel}}(\text{Sing}_k(U), \mathbb{Z})\end{aligned}$$

where

$$\begin{aligned}\text{Sing}_k(U) &= \text{singular } k\text{-chains on } U \\ &= \langle \sigma : \Delta^k \rightarrow U \rangle_{\text{free, Abel}}\end{aligned}$$

and  $\widetilde{\mathcal{S}}^k := (\mathcal{S}^k)^{\text{sh}}$  is called the sheaf of singular cochains.

Def

$$H_{\text{sing}}^k(X, \mathbb{Z}) := H^k(\mathcal{S}(X))$$

Thm For  $X$  loc contractible,

$$H^k(X, \mathbb{Z}) \cong H_{\text{sing}}^k(X, \mathbb{Z})$$

Sketch of the wrong proof: Still hard. I don't check details.

1. Construct a complex of sheaves

$$0 \longrightarrow \underline{\mathbb{Z}} \longrightarrow \widetilde{\mathcal{S}}^0 \longrightarrow \widetilde{\mathcal{S}}^1 \longrightarrow \dots \quad (*)$$

2. Show that  $(*)$  is exact when  $X$  is loc contractible.  $\Rightarrow \underline{\mathbb{Z}} \cong \widetilde{\mathcal{S}}^0$

3. Show that  $\widetilde{\mathcal{S}}^k$  is flabby, then

$$H^k(X, \mathbb{Z}) \cong H^k(\widetilde{\mathcal{S}}^k(X))$$

Reduced to show:  $H^k(\widetilde{\mathcal{S}}^k(X)) \cong H^k(\mathcal{S}^k(X))$

4. Consider the exact sequence of chain complexes

$$0 \longrightarrow \mathcal{S}^k(X)_\circ \longrightarrow \mathcal{S}^k(X) \longrightarrow \widetilde{\mathcal{S}}^k(X) \longrightarrow \mathcal{S}^k(X)^0 \longrightarrow 0$$

shows that:

$$\textcircled{1} \quad \mathcal{S}^k(X)^0 = 0 \quad \text{This is wrong. We ignore this bug...}$$

$$\textcircled{2} \quad \mathcal{S}^k(X)_\circ = \left\{ \alpha \in \mathcal{S}^k(U) \mid \begin{array}{l} \exists \text{ open covering } \{U_i\}_i \text{ of } U \text{ s.t.} \\ \alpha|_{U_i} = 0 \quad \forall i \end{array} \right\}$$

$$\textcircled{3} \quad H^k(\mathcal{S}^k(X)_\circ) = 0$$

Finally,  $H^k(X, \mathbb{Z}) \cong H^k(\widetilde{\mathcal{S}}^k(X)) \cong H^k(\mathcal{S}^k(X)) \stackrel{\text{def}}{=} H_{\text{sing}}^k(X, \mathbb{Z})$ .

Q. Can one shows  $H^k(\mathcal{S}^k(X)^0) = 0$  to replace the bug in 4.①?