Week 9: Anomalies and Wess-Zumino consistency conditions

	Discussion of outline	Discussion of talk	Your talk
Important dates	before 04.12.2015	before 11.12.2015	18.12.2015

Your seminar talk should roughly cover the following keywords and concepts:

- Anomalies as terms spoiling classical conservation laws
- Examples (not all to be detailed):
  - Chiral anomaly (broken chiral U(1))
  - Conformal anomaly, also known as scale or Weyl anomaly (the reason for the need to consider renormalization group flows)
  - Gauge anomaly (would spoil consistency, needs to vanish, does so in the standard model)
  - Gravitational anomaly (including the failure of modular invariance, i.e. the non-invariance under large diffeomorphisms such as Dehn twists etc.)
- Origin in path integral formulation: Non-invariance of path integral measure
- Abelian and non-abelian anomalies
- Global vs. local anomalies (the former refer to "large gauge transformations", disconnected from the identity)
- Relation to indices of Fredholm operators and topology (importance of zero modes)
- Anomalies from Feynman diagrams
- Physical implications for selected examples
- Wess-Zumino consistency conditions as a systematic way of constructing *candidates* for anomalies. Only include details if there is enough time and if this can be cast in a pedagogical form.

Important aspects that should be emphasized:

- An anomaly is a violation of a classical symmetry upon the quantization of a system. It originates from the need to break the symmetry when regularizing otherwise ill-defined expressions (e.g. the path integral measure or determinants of infinite operators). When removing the regulator at the end of a calculation, the symmetry may or may not be restored, depending on whether the theory anomalous or not.
- The Wess-Zumino consistency conditions allow for a systematic construction of possible terms which arise as anomalies. However, in a concrete theory one would still need to determine the prefactor (which may well be zero).

Remarks:

- It is your task to turn the material related to your topic into a coherent story. This requires a detailed examination and understanding of the subject. Merely giving definitions without motivation and without pointing out the bigger picture is not sufficient.
- You will realize that time is rather limited and that you will need to focus on essentials.
- Personally, I am using 6-7 handwritten A4 pages for a 90 minutes lecture. It is recommended to aim at no more than 4-5 pages for your own presentation (and do not try to gain extra space by writing extra small).
- Please emphasize the physical ideas, not the mathematical formalism. Also avoid detailed calculations (except where they add to the conceptual understanding).
- In the two preparatory meetings you will be able to get feedback and assistance by your supervisor before you give your presentation, both on content and style. In order to maximize the benefit of these meetings it is important that you are well prepared.

References:

- For the treatment of anomalies using the path integral I would suggest Nakahara [1], Chapter 13 (only the first part and focusing on the abelian anomaly for the calculation)
- A heat kernel treatment is given in the book of Ramond [2, Chapter 8.9]
- For a different perspective one may, in addition, read Göckeler and Schücker [3], Chapter 12 (potentially also Chapter 13)
- Sometimes he tries to be overly general and notations are hard to grasp but Weinberg is always worth a read [4, Chapter 22]
- Some discussion in the context of the standard model is contained in Chapter 30.4 in the book of Schwartz [5]
- Wikipedia (to get a quick overview)
  - Anomaly (physics)

References

[1] M. Nakahara, Geometry, Topology and Physics. Taylor & Francis, 2nd ed., 2003.

[2] P. Ramond, Field Theory: A Modern Primer. 2nd ed., Westview.

[3] M. Göckeler and T. Schücker, Differential Geometry, Gauge Theories, and Gravity. Cambridge University Press, 1987.

[4] S. Weinberg, The Quantum Theory of Fields. Cambridge University Press, 2004.

[5] M. D. Schwartz, Quantum Field Theory and the Standard Model. Cambridge University Press, 2014.