Proseminar

Conformal Field Theory and String Theory

ORGANISER: Prof. Matthias Gaberdiel

The topics are organized in two main parts: **Part I** deals with conformal field theory, in particular two-dimensional conformal field theory, while **Part II** is concerned with string theory. The topics labelled by [B] are more introductory and can also be done by Bachelor students. We have given a preliminary list of suggested references for each topic; for more specific guidance to the literature, please ask your project supervisor.

PART I: CONFORMAL FIELD THEORY

1. **The conformal group in various dimensions [B] — 4 March 2013, 10.00**
   (Student: Henrik Dreyer, Tutor: Andrei Levedev, `lebedev@itp.phys.ethz.ch`**)**

   - Global conformal transformations
   - The structure of infinitesimal conformal transformations
   - The Virasoro algebra in 2 dimensions

   References:

   - P. Ginsparg, *Applied conformal field theory,* chapter 1 & 2, `http://arxiv.org/abs/hep-th/9108028`.

   - M. Schottenloher, *A mathematical introduction to conformal field theory,* Lecture Notes in Physics **759**, Springer (2008).

   - P. Di Francesco, P. Mathieu, D. Senechal, *Conformal Field Theory,* Springer (1997), chapter 4 & 5.

   - R. Blumenhagen, E. Plauschinn, *Introduction to conformal field theory,* Springer (2009).

2. **Basic properties of CFTs and examples [B] — 4 March 2013, 11.30**
   (Student: Daniel Herr, Tutor: Andrei Levedev, `lebedev@itp.phys.ethz.ch`**)**

   - Structure of energy momentum tensor in conformal field theories
   - Structure of correlation functions
   - The free boson and free fermion in 2d (with calculation of central charge)

References:

- P. Ginsparg, *Applied conformal field theory,* chapter 1 & 2, http://arxiv.org/abs/hep-th/9108028.

- P. Di Francesco, P. Mathieu, D. Senechal, *Conformal Field Theory,* Springer (1997), chapter 4-6.

3. **Operator product expansions [B] — 4 March 2013, 14.00**
(Student: Pascal Debus, Tutor: Jawei Mei, meij@itp.phys.ethz.ch**)**

   - Radial quantisation
   - Operator product expansion
   - Commutation relations from OPEs
   - Highest weight representations and descendants

   References:

   - P. Ginsparg, *Applied conformal field theory,* chapter 2 & 3, http://arxiv.org/abs/hep-th/9108028.

   - D. Lüst, S. Theisen, *Lectures on string theory*, Lecture notes in physics, Springer (1989), §4.

4. **Statistical Mechanics and minimal models [B] — 11 March 2013, 10.00**
(Student: Paolo Molignini, Tutor: Sebastian Schmidt, schmidts@phys.ethz.ch**)**

   - Lattice models and continuum limit
   - Critical exponents
   - Ising model

   References:

   - P. Di Francesco, P. Mathieu, D. Senechal, *Conformal Field Theory,* Springer (1997), chapter 3, 6, 7 & 12.

   -P. Ginsparg, *Applied conformal field theory,* chapter 7, http://arxiv.org/abs/hep-th/9108028.

   - J. Cardy, *Conformal Invariance and Statistical Mechanics*, in "Fields, strings and critical phenomena: Les Houches: session XLIX," eds. E. Brézin, J. Zinn-Justin, North Holland (1990); http://www-thphys.physics.ox.ac.uk/people/JohnCardy/lh.pdf.

   - A.A. Belavin, A.M. Polyakov, A.B. Zamolodchikov, *Infinite conformal symmetry in two-dimensional quantum field theory*, Nucl. Phys. B **241**, 333 (1984).

5. **Basics of Lie theory [B] — 11 March 2013, 11.30**
(Student: Andreas Wieser, Tutor: Peter Vrana, vrana@itp.phys.ethz.ch**)**

   - Simple Lie algebras
   - Cartan Weyl basis and roots
   - Classification of finite Lie algebras, Dynkin diagrams

- Lie groups

References:

- J. Fuchs, C. Schweigert, *Symmetries, Lie Algebras and Representations,* Cambridge Monographs on Mathematical Physics, (1997).

- W. Fulton, J. Harris, *Representation theory,* Springer (1991), part IV, chapters 21, 22.

- B.C. Hall, *Lie groups, Lie algebras, and representations: an elementary introduction*, Springer (2004), chapters 5, 6, 7.1, 7.2, 8.

6. **WZW models — 11 March 2013, 14.00**
(Student: Julian Kern, Tutor: Jawei Mei, `meij@itp.phys.ethz.ch`**)**

   - The WZW action
   - Current symmetries
   - Affine Kac-Moody algebras and the Sugawara construction

   References:

   - P. Goddard, D.I. Olive, *Kac-Moody and Virasoro algebras in relation to quantum physics*, Int. J. Mod. Phys. A **1**, 303 (1986).

   - P. Di Francesco, P. Mathieu, D. Senechal, *Conformal Field Theory,* Springer (1997), chapter 6 & 14-15.

   - P. Ginsparg, *Applied conformal field theory,* chapter 9, `http://arxiv.org/abs/hep-th/9108028`.

7. **Modular invariance and orbifolds [B] — 18 March 2013, 10.00**
(Student: Stefan Huber, Tutor: Martin Fraas, `mfraas@phys.ethz.ch`**)**

   - The modular group $SL(2,\mathbb{Z})$
   - CFT on a torus
   - Orbifolds

   References:

   - P. Di Francesco, P. Mathieu, D. Senechal, *Conformal Field Theory,* Springer (1997), chapter 10.

   - P. Ginsparg, *Applied conformal field theory,* chapter 8, `http://arxiv.org/abs/hep-th/9108028`

   - J. Cardy, *Conformal Invariance and Statistical Mechanics*, in "Fields, strings and critical phenomena: Les Houches: session XLIX," eds. E. Brézin, J. Zinn-Justin, North Holland (1990); `http://www-thphys.physics.ox.ac.uk/people/JohnCardy/lh.pdf`.

8. **Conformal perturbation theory and the c-theorem — 18 March 2013, 11.30**
(Student: Ramon Murmann, Tutor: Sebastian Schmidt, `schmidts@phys.ethz.ch`**)**

   - General perturbation theory of conformal field theories
   - The c-theorem

- Perturbation of minimal models by (1,3) field

References:

- J. Cardy, *Conformal Invariance and Statistical Mechanics*, in "Fields, strings and critical phenomena: Les Houches: session XLIX," eds. E. Brézin, J. Zinn-Justin, North Holland (1990); `http://www-thphys.physics.ox.ac.uk/people/JohnCardy/lh.pdf`.

- A.B. Zamolodchikov, *Irreversibility of the flux of the renormalisation group in a 2D field theory*, JETP Lett. **43**, 731 (1986).

- A.B. Zamolodchikov, *Conformal symmetry and multicritical points in two-dimenisonal quantum field theory*, Sov. J. Nucl. Phys. **44**, 530 (1986).

- A.W.W. Ludwig, J.L. Cardy, *Perturbative evaluation of the conformal anomaly at new critical points with applications to random systems,* Nucl. Phys. B **285**, 687 (1987).

9. **Fusion Rules and the Verlinde Formula [B] — 25 March 2013, 10.00**
(Student: Stephanie Mayer, Tutor: Matthias Gaberdiel, `gaberdiel@itp.phys.ethz.ch`**)**

   - Fusion rules from differential equations
   - Fusion rules for the minimal models
   - Relation to modular transformation matrix and Verlinde formula

   References:

   - P. Di Francesco, P. Mathieu, D. Senechal, *Conformal Field Theory,* Springer (1997), chapter 8.3, 8.4 and 10.8

10. **Boundary conformal field theory — 25 March 2013, 11.30**
(Student: Zhuli He, Tutor: Adel Benlagra, `benlagra@itp.phys.ethz.ch`**)**

    - Conformal invariance in the presence of a boundary
    - Boundary states
    - Cardy condition
    - The g-function

    References:

    - V. Schomerus, *Lectures on branes in curved backgrounds,* Class. Quant. Grav. **19**, 5781 (2002) `[arXiv:hep-th/0209241]`.

    - J.L. Cardy, *Effect of boundary conditions on the operator content of two-dimensional conformally invariant theories,* Nucl. Phys. B **275**, 200 (1986).

    - J.L. Cardy, *Boundary conditions, fusion rules and the Verlinde formula,* Nucl. Phys. B **324**, 581 (1989).

    - I. Affleck, A.W.W. Ludwig, *Universal noninteger 'ground state degeneracy' in critical quantum systems,* Phys. Rev. Lett. **67**, 161 (1991).

11. **Fibonacci anyons and topological quantum computers [B] — 25 March 2013, 14.00 (Student: Christos Charalambous,**
Tutor: Alexei Soluyanov, `soluyanov@itp.phys.ethz.ch`**)**

- Topological quantum computers
- $\mathfrak{su}(2)$ level 2 WZW-model

References:

- C. Nayak et al, *Non-Abelian Anyons and Topological Quantum Computation*, http://arxiv.org/pdf/0707.1889v2.

- J. Preskill, *Quantum Computation*, http://www.theory.caltech.edu/~preskill/ph219/topological.pdf.

- P. Di Francesco, P. Mathieu, D. Senechal, *Conformal Field Theory,* Springer (1997), chapter 15.

12. **Logarithmic conformal field theory — 8 April 2013, 10.00**
(Student: Fabio D'Ambrosio, Tutor: Martin Fraas, mfraas@phys.ethz.ch**)**

    - The $c = -2$ example
    - Percolation

    References:

    - V. Gurarie, *Logarithmic operators in conformal field theory,* Nucl. Phys. B **410**, 535 (1993) [arXiv:hep-th/9303160].

    - V. Gurarie, A.W.W. Ludwig, *Conformal field theory at central charge c=0 and two-dimensional critical systems with quenched disorder,* In Shifman, M. (ed.) et al.: From fields to strings, vol. 2, 1384-1440 [arXiv:hep-th/0409105].

    - J.L. Cardy, *Lectures on conformal invariance and percolation,* arXiv:math-ph/0103018.

13. **From SLE to conformal field theory — 8 April 2013, 11.30**
(Student: Christoph Müller, Tutor: Volkher Scholz, scholz@phys.ethz.ch**)**

    - SLE approach towards conformal field theory

    References:

    - J.L. Cardy, *SLE for theoretical physicists,* Annals Phys. **318**, 81 (2005) [arXiv:cond-mat/0503313].

    - M. Bauer, D. Bernard, *2D growth processes: SLE and Loewner chains,* Phys. Rept. **432**, 115 (2006) [arXiv:math-ph/0602049].

14. **Entanglement entropy in conformal field theory [B] — 8 April 2013, 14.00**
(Student: Matthias Strodtkötter, Tutor: Volkher Scholz, scholz@phys.ethz.ch**)**

    - Entanglement entropy in quantum field theory
    - application to 2d conformal field theory

    References:

    - P. Calabrese and J.L. Cardy, *Entanglement entropy and quantum field theory: A Non-technical introduction,* Int. J. Quant. Inf. **4**, 429 (2006) [arXiv:quant-ph/0505193].

    - P. Calabrese and J.L. Cardy, *Entanglement entropy and conformal field theory,* arXiv:0905.4013 [cond-mat].

PART II: STRING THEORY

1. **Classical String Theory [B] — 15 April 2013, 10.00**
   (Student: David Reuter, Tutor: Kewang Jin, `jinke@phys.ethz.ch`**)**

   - The Polyakov and the Nambu-Goto action
   - Classical string solutions and their properties

   References:

   - B. Zwiebach, *A first course in string theory,* CUP (2004).

   - D. Lüst, S. Theisen, *Lectures on string theory*, Lecture notes in physics, Springer (1989), §2.

   - M.B. Green, J.H. Schwarz, E. Witten, *Superstring theory I & II*, Cambridge University Press (1987) and (1988), §2.1.

2. **Light-cone quantisation of bosonic string [B] — 15 April 2013, 11.30**
   (Student: Nuhro Ego, Tutor: Kewang Jin, `jinke@phys.ethz.ch`**)**

   - Light cone gauge
   - Quantisation, D=26 from Lorentz symmetry

   References:

   - B. Zwiebach, *A first course in string theory,* CUP (2004).

   - D. Lüst, S. Theisen, *Lectures on string theory*, Lecture notes in physics, Springer (1989), §3.2, 3.3.

   - M.B. Green, J.H. Schwarz, E. Witten, *Superstring theory I & II*, Cambridge University Press (1987) and (1988), §2.3.

   - P. Goddard, J. Goldstone, C. Rebbi, C.B. Thorn, *Quantum dynamics of a massless relativistic string*, Nucl. Phys. B **56**, 109 (1973).

3. **Covariant quantisation and no-ghost theorem — 15 April 2013, 14.00**
   (Student: Kirill Streltsov, Tutor: Constantin Candu, `canduc@phys.ethz.ch`**)**

   - Canonical quantisation
   - Virasoro algebra and physical state condition
   - the No-ghost Theorem

   References:

   - M.B. Green, J.H. Schwarz, E. Witten, *Superstring theory I & II*, Cambridge University Press (1987) and (1988), §2.2.1, 2.2.2 & 2.3.3.

   - D. Lüst, S. Theisen, *Lectures on string theory*, Lecture notes in physics, Springer (1989).

   - P. Goddard, C.B. Thorn, *Compatibility of the dual Pomeron with unitarity and the absence of ghosts in the dual resonance model*, Phys. Lett. B **40**, 235 (1972).

4. **Low energy effective actions from string theory — 29 April 2013, 10.00**
(Student: Sam Guns, Tutor: Marius De Leeuw, deleeuwm@itp.phys.ethz.ch**)**

   - Non-linear sigma models
   - Worldsheet versus target space
   - The emergence of gravity

   References:

   - B. Zwiebach, *A first course in string theory,* CUP (2004).

   - D. Tong, *String Theory,* arXiv:0908.0333 [hep-th], §7.

   - C. Callan, L. Thorlacius, *Sigma models and string theory*, http://www.damtp.cam.ac.uk/user/tong/string/sigma.pdf.

   - M.B. Green, J.H. Schwarz, E. Witten, *Superstring Theory I & II,* CUP (1987) and (1988).

   - J. Polchinski, *String Theory I,* CUP (1998), Chapter 3.7.

5. **Compactification on tori and T-duality [B] — 29 April 2013, 11.30**
(Student: Florian Johne, Tutor: Johannes Brödel, jbroedel@itp.phys.ethz.ch**)**

   - Basics of compactification
   - T-duality of the string spectrum

   References:

   - B. Zwiebach, *A first course in string theory,* CUP (2004).

   - J. Polchinski, *String Theory I,* CUP (1998), Chapter 8.

6. **Superconformal Strings — 13 May 2013, 10.00**
(Student: Francesca Ferrari, Tutor: Cristian Vergu, verguc@itp.phys.ethz.ch**)**

   - The NS-R action and its symmetries
   - $\mathcal{N} = 1$ superconformal algebra, and the physical state condition
   - Covariant and light-cone quantisation of the NS-R action

   References:

   - D. Lüst, S. Theisen, *Lectures on string theory*, Lecture notes in physics, Springer (1989), §7 & §8.

   - M.B. Green, J.H. Schwarz, E. Witten, *Superstring theory I & II*, Cambridge University Press (1987) and (1988), §4.1 - 4.3.

7. **Superstrings — 13 May 2013, 11.30**
(Student: Imre Majer, Tutor: Cristian Vergu, verguc@itp.phys.ethz.ch**)**

   - GSO-projection, spin structures and modular invariance
   - Type II theories and their spectrum
   - Green-Schwarz formulation

References:

- D. Lüst, S. Theisen, *Lectures on string theory*, Lecture notes in physics, Springer (1989), §8 & §9.

- M.B. Green, J.H. Schwarz, E. Witten, *Superstring theory I & II*, Cambridge University Press (1987) and (1988), §4.3.3, §5.3.

8. **The Heterotic String — 27 May 2013, 10.00**
(Student: Andrea Ferrari, Tutor: Johannes Brödel, `jbroedel@itp.phys.ethz.ch`**)**

   - Construction of the two 10-dimensional heterotic string theories
   - Modular invariance

   References:

   - D. Lüst, S. Theisen, *Lectures on string theory*, Lecture notes in physics, Springer (1989), §10.

   - M.B. Green, J.H. Schwarz, E. Witten, *Superstring theory I & II*, Cambridge University Press (1987) and (1988).

   - D.J. Gross, J.A. Harvey, E.J. Martinec, R. Rohm, *Heterotic string theory 1. The free heterotic string*, Nucl. Phys. B **256**, 253 (1985).

9. **D-branes — 27 May 2013, 11.30**
(Student: Miguel Garcia, Tutor: Kewang Jin, `jinke@phys.ethz.ch`**)**

   - String boundary conditions and a first glance at D-branes
   - T-duality for open strings
   - Gauge theories confined to D-branes
   - The Dirac-Born-Infeld action

   References:

   - B. Zwiebach, *A first course in string theory,* CUP (2004).

   - J. Polchinski, *String Theory I,* CUP (1998), Chapter 8.

   - K. Becker, M. Becker, J. Schwarz, *String Theory and M-Theory - A Modern Introduction,* CUP (2007).

   - D. Tong, *String Theory,* `arXiv:0908.0333 [hep-th]`, §3.

10. **The Gauge/Gravity Correspondence — 27 May 2013, 14.00**
(Student: Kevin Ferreira, Tutor: Cristian Vergu, `verguc@itp.phys.ethz.ch`**)**

    - $\mathcal{N} = 4$ gauge theory on D3 branes
    - Anti-de Sitter space
    - Holography
    - Basics of the correspondence - $\mathrm{AdS}_5/\mathrm{CFT}_4$

References:

- B. Zwiebach, *A first course in string theory,* CUP (2004).

- I. Klebanov, *Introduction to the AdS/CFT Correspondence, TASI Lectures,* `http://arXiv.org/pdf/hep-th/0009139`.

- A. Zaffaroni, *Introduction to the AdS-CFT correspondence,* Class. Quant. Grav. **17**, 3571 (2000).

- K. Becker, M. Becker, J. Schwarz, *String Theory and M-Theory - A Modern Introduction,* CUP (2007).

- J. Edelstein, R. Portuges, *Gauge/String Duality in Confining Theories,* Chapter 2, `http://arXiv.org/abs/hep-th/0602021v4`.