Naturprinzip und Biomimetik:
Wie haften Geckos und Fliegen an der Decke?
Surfaces and Interfaces

- sensorics
- attachment
- drag reduction
- optics (anti-reflection)
- grinding
- anti-friction
- sound generation
- respiration
- thermoregulation
- coloration pattern
- self-cleaning
- etc., etc.

Romalea microptera
Goals

**to understand functional principles**
- studies on ultrastructure, material properties, force range, motion in biological systems

**to develop methods**
- microscopy techniques, measurements of stiffness, hardness, adhesion, friction at local and global scales

**to understand evolutionary tendencies**
- broad comparative studies

**to find interesting properties of systems**
- transfer of the natural design solutions in the material science

**EVOLUTIONARY PROJECTS**

**FUNCTIONAL PROJECTS**

**BIOMIMETICS PROJECTS**
Get a Grip

The gecko owes its superior climbing skills to atomic power

BioBriefs

GECKOS YIELD THEIR STICKY SECRETS

For more than a century, researchers have been trying to figure out how geckos can walk on any surface in any direction. The mystery is, what makes geckos stick to just about anything a question that has puzzled scientists for decades. Now, a study has finally shed light on this phenomenon.

A (Non)Sticky Situation: How Geckos Climb Up Walls and Why We Should Care

Tiny suction cups that can stick up walls and across ceilings... a step non-chemical "glue" to build tomorrow's smallest machines... an alternative to rubber. Their results were published in a recent issue of the journal Nature (vol. 405, June 8, 2000).

Gecko feet may be step toward strange technologies

USA TODAY

PORTLAND, Ore. [AP] - The mystery of what makes geckos stick to just about anything a question that has puzzled scientists for decades. Now, a study has finally shed light on this phenomenon.

Autumn et al. 2000; 2002; 2006
What Material Do We Want to Develop?

Sticky...

Do we want to use it for walking on the wall and ceiling?

...and extremely fast
...to unpredictable surfaces
...and fast releasable (millions of cycles)
...non-conglutinating!
Ceiling Situation (Static)
Ceiling Situation

- friction
- adhesion
- weight

Contact formation → strong adhesion → contact breakage
- fast
- reliable
- minimal load on the ceiling
- fast
- minimal force
Insect Terrain
Two Designs of Animal Attachment Pads

over 300 species studied
Dimension and Density of Setae

Dependence of the hair density (terminal elements) of the attachment pads on the body mass in hairy pad systems of representatives from diverse animal groups.

Setal density dependence on the body mass

Scherge and Gorb, 2001 Springer Book
Arzt, Gorb, Spolenak, 2003, PNAS
Experiment with the Structured Polymer Surface

Peressadko and Gorb, 2004, J. Adhesion
First Prototypes
Contact Shape


A. Bug *Pyrrhocoris apterus*, smooth pulvillus

B. Grasshopper *Tettigonia viridissima*, surface of the attachment pad

C. Fly *Myathropa florea*, unspecialised hairs on the leg

D. Fly *Calliphora vicina*, seta of the pulvilli

E. Beetle *Harmonia axyridis*, seta of the second tarsal segment

F. Beetle *Chrysolina fastuosa*, seta of the second tarsal segment

G. Male beetle *Dytiscus marginatus*, suction cups on the ventral side of the foreleg tarsi
Function of Terminal Elements

*Gekko gecko*


Functions: (1) Low bending stiffness of thin terminal plates enables an intimate contact with surface irregularities. (2) Easy contact formation by sliding. (3) Increasing of contact forces without normal load.
Gradient Materials

Box-and-Whisker plots showing the mean (n = 50) Young’s modulus of fresh (A) and dry (B) adhesive tarsal setae from the second adhesive pads of first legs of female *Coccinella septempunctata* obtained by 38 AFM indentations (1 µm spacing) along each seta. The borders of the boxes define the 25th and 75th percentiles, the median is indicated by a horizontal line, and the error bars define the 10th and 90th percentiles. (n.s. = not significant, *** = highly significant.)

- Indentation depth: 50 nm
- Spring constant: 25 N m⁻¹
- Tip radius: 10 nm
- 38 sites per hair
- Distance between sites: 1 µm
- 100 individual setae
Challenge: to put all this together

- dimension and density
- aspect ratio
- slope
- hierarchy
- shape of the contact
- asymmetry
- proper movements (during attachment and detachment)
- gradient materials
- non-conglutination
GOTTLIEB BINDER INNOVATES FASTENING SYSTEMS

wide range of applications for various fastening systems

Mushroom-Shaped Adhesive MicroStructure (MSAMS)

HOOK AND LOOP

MUSHROOM FASTENER

DUOTEC®

MICROPLAST®

GECKO®
MSAMS: Bioinspired Features

**BIOINSPIRED FEATURES**
- contact subdivision
- hexagonal pattern
- thin plate-like head
- joint-like neck
- high aspect ratio

**FUNCTION**
- increase of the total perimeter of contact
- prevention of the crack propagation
- tolerance to the contamination
- the highest packaging density of structures
- tolerance to the contamination
- prevention of the crack propagation
- adaptability to uneven surfaces
- decrease of stored elastic energy
MSAMS in Action


- **BK**, backing
- **DP**, dust particle
- **LP**, lip at the margin of the pillar tip
- **NR**, narrowing of the pillar close to the tip
- **PL**, pillars
- **SH**, shaft
Enhanced adhesion of mushroom-shaped microstructure relies on combination of van der Waals forces and crack-trapping mechanism (e.g. Hui et al. 2004, J. R. Soc. Interface; Carbone et al. 2011, Soft Matter)

Daltonio et al. 2005, CLAWAR
Gorb et al. 2007, J. R. Soc Interface
Varenberg, Gorb 2007, J. R. Soc Interface
Gorb, Varenberg 2007, JAST
Del Campo et al. 2007, Langmuir
Varenberg, Gorb 2008a, J. R. Soc Interface
Varenberg, Gorb 2008b, J. R. Soc Interface
Murphy et al. 2009, Appl. Mater. Interfaces
Murphy et al. 2009, Small
Kim et al. 2009, Langmuir

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MSAMS Adhesion


![Diagram showing adhesion strength comparison](image)
Contamination of MSAMS


Graphs showing the % of initial force over the number of cycles for structured and smooth surfaces. The graphs also show the % of initial force after 300 cycles and after washing.
Wall Walking Using MSAMS

Daltorio et al., 2005, CLAWAR Conference

with Daltorio, Horchler, Ritzmann, Quinn
Case Western Reserve University, Cleveland, OH, USA
2010 – MSAMS in Pick-and-Drop Process

LEGO toy-robot at Hannover Fair 2010

120 cycles per h
960 per day
4800 during 5 days without cleaning

Company FESTO
2011 constructed first commercial flat gripping device based on MSAMS: long-term test = about 20 Mio cycles
Crazy Tape Holds Weight of Man:

Insects inspire mother of all adhesives

University of Kiel’s Super-Adhesive Takes Inspiration from Beetles

A new tape uses some of nature’s tricks to stick

Biologically inspired adhesive tape can be reused thousands of times

Bioinspired Dry Tape Brings Spider-Man A Little Closer
Industrial Collaboration

Bio-Inspired Adhesives

Adhesion Reduction

[Images of historical and modern adhesion and adhesive technology]
Industrial Collaboration

Biologically Inspired Surfaces for Haptics
Expertise

Microscopy Techniques
- Cryo Scanning Electron Microscope Hitachi 4800 with Gatan Cryo Prep. System
- Transmission Electron Microscope (FEI Tecnai), Cryotomy and Ultramicrotomy
- Fluorescence Microscopy
- μCT (SkyScan, 0.7 μm resolution)

Surface Characterisation
- White Light Interferometer Zygo New View 6000
- High Speed Contact Angle Measurement Device, Dataphysics OCA-200
- 2 Confocal Laser Scanning Microscopes, Zeiss CLSM 410 and 710
- AFM JPK Nano-Wizard
- Nanoindenter MTS SA2
- Surface energy estimation (Dataphysics OCA-200)

Adhesion and Friction Measurements
- Microtribotesters Basalt 01, Basalt 02, Basalt 03, (MUST, Tetra)
- Custom Made Microtribotester Based on WP-100
- AFM JPK Nano-Wizard

Motion Analysis
- High-Speed Videorecording (Photon Fastcam SA4 and ULTIMA, up to 200.000 fps)
Structure and Function of Adhesive Pads

Dr. Constanze Grohmann
Jonas Wolff


Philodromus dispar
Adhesion Control During Locomotion

Philipp Busshardt


Carausius morosus
Underwater Adhesion

Dr. Thomas Kleinteich
Secretory Fluids: AFM


Dr. Henrik Peisker
Adhesion of Parasites

Wong, Michels, Gorb, 2012. J. Parasitology
Clamp Structures

Dr. Jana Willkommen

cerci

paraproct

250 µm
Anti-Adhesive Surfaces in Plants

Dr. Elena Gorb
Julia Purto
Nadine Jacky
Martina Baum

Gorb et al., 2010. J.R.S. Interface

Nepenthes alata

smooth surface

reduction of the real contact area

waxy surface

pad contamination

fluid absorption

increase of the fluid layer thickness

setal tip of Chrysolina fastuosa

2 cm
Ommatidia Gratings: AFM


Dr. Henrik Peisker

Laothoe populi

Volucella pellucens

Aeshna mixta
Ommatidia Gratings: AFM


<table>
<thead>
<tr>
<th></th>
<th>A. mixta</th>
<th>L. populi</th>
<th>V. pellucens</th>
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</thead>
<tbody>
<tr>
<td>Calculated $F_{pull-off}$ [µN] (control)</td>
<td>3.3</td>
<td>2.9</td>
<td>2.5</td>
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<tr>
<td>Measured $F_{pull-off}$ [µN] (control)</td>
<td>1.2</td>
<td>1.9</td>
<td>0.9</td>
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<tr>
<td>Calculated $F_{pull-off}$ [nN] (ommatidia)</td>
<td>-</td>
<td>90</td>
<td>23</td>
</tr>
<tr>
<td>Measured $F_{pull-off}$ [nN] (ommatidia)</td>
<td>178</td>
<td>77</td>
<td>19</td>
</tr>
</tbody>
</table>

![Diagram showing adhesion forces for different species and sphere sizes.](image)
Sliding Locomotion: Frictional Anisotropy

Berthé, Westhoff, Bleckmann, Gorb, 2009
Snakes: Friction Control

Martina Baum

Lampopeltis getula

μ

Cushioned
Uncushioned

Caudal
Cranial
Dextral
Sinistral

0.08
0.16
0.08
0.09
0.16
0.15
0.15
0.13

*
Snakes: Wear Resistance

Marie-Christin Klein

Klein and Gorb, 2012, J.R.S. Interface

Gongylophis colubrinus

~15 μm

modulus [Gpa]

outside

inside

0 400 800 1200 1600 2000

displacement into surface [nm]
Contact Mechanics at Microscale

Lars Heepe
Emre Kizilkan


![Graph showing pull-off force vs. velocity with different conditions and material types.](image)
Wet Adhesion

Dr. Alexander Kovalev

Dragonfly Wing Microjoints

Esther Appel

Gradient Materials


Centropages hamatus
Phase 2 – Research Topic R4: Ocean Innovation

How can ocean biological substances and material be used to support technological innovations for a range of applications benefitting human society?
Phase 2 – Research Topic R4: Ocean Innovation

**Screening:** Surface geometry, material composition and properties

- copepod *Centropages hamatus*
- fish *Gobeisox meandricus*
- sea urchin *Paracentrotus lividus*

J. Michels, T. Kleinteich, S. Gorb