

Index

Note: Page numbers in *italics* and **bold** refers to figures and tables respectively.

a

- ABAC. *see* attribute-based access control (ABAC)
- ABB 150
- academic labs 221, 232–233
- academic research 9, 70–72, 142
- additive manufacturing 189, 190–192
- ADF. *see* Allotrope Data Format (ADF)
- advanced encryption standard (AES) 257
- advanced persistent threat (APT) 247
- AES. *see* advanced encryption standard (AES)
- AFO. *see* Allotrope Foundation Ontology (AFO)
- Agilent ChemStation 111
- AGREEprep tool 218
- AGREE tool 218
- AI. *see* artificial intelligence (AI)
- Allen-Bradley ControlLogix series 162
- Allotrope Data Format (ADF) 77, 97–99, 112–113
- Allotrope Foundation 96, 101
- Allotrope Foundation Ontology (AFO) 99
- Allotrope Simple Model (ASM) 97–99, 112–113
- Amazon Web Services (AWS) 229
 - IoT 55
- AMS. *see* asset management software (AMS)
- analytical chemistry 67, 102, 228
- analytical devices 159
- Analytical Information Markup Language (AnIML) 77, 97–99, 112–113, 135
- angle of rotation of joints 150–151
- angular grippers 152–153
- AnIML. *see* Analytical Information Markup Language (AnIML)
- anticancer infusion solution, preparation of 2, 2
- application layer 78
- APT. *see* advanced persistent threat (APT)
- Arduino 125
- articulated robots 149–150
- artificial intelligence (AI) 47, 84, 88, 141–142, 223–227
 - electronic laboratory notebook 33–34
 - laboratory 47
 - revolutionizing analytical methods 225–227
- ArtiMinds 157, 165
- ASM. *see* Allotrope Simple Model (ASM)
- asset management software (AMS) 122, 128
- atline analysis system
 - automation 133–134
 - dataflow 135–136
 - device integration 136–137
 - middleware 136
 - orchestration 134–135, 134
- attribute-based access control (ABAC) 256
- automated blood analyser 146

automatic laboratory 47
 automatic tool changer 156
 automation, 12–13, 52, 107, 202, 223–225.
 see also Center for Life Science
 Automation (CELISCA); flexible
 automation; lab/laboratory automation
 in academic environment 173–177
 autosampler 4, 52, 159
 AWS. *see* Amazon Web Services (AWS)

b

binary Hierarchical Data Format 98
 bioconductor 112
 black box approach 105

c

CAD. *see* computer-aided design (CAD)
 capillary chromatography 185, 186
 capillary liquid chromatography (cLC) 182
 carcinogenic, mutagenic, reprotoxic (CMR)
 agents 1–2
 CELISCA. *see* Center for Life Science
 Automation (CELISCA)
 Center for Life Science Automation
 (CELISCA) 8–14
 chemotherapy 2
 Chemotion 24–28
 chromatographic methods 182–183, 195,
 225
 ChromSword 227
 CHRONOS software 134, 136–137
 circular economy 66–67, 203, 205, 230
 cLC. *see* capillary liquid chromatography
 (cLC)
 cloud servers 54
 COBIT. *see* control objectives for
 information and related technology
 (COBIT)
 CoboVox 157–158
 collaboration 21
 collaborative robots (cobots) 148–151,
 156–158, 164, 177
 commercial IoT platform 55–56
 communication layer 78–79
 communication standards
 communication layer 78–79
 data format standards 77
 device communication 77–78

device integrator 92–93
 LADS 84–91
 LADS OPC UA 79–81
 SiLA 81–84
 SiLA 2, 79–81
 computer-aided design (CAD) 177, 193
 control objectives for information and
 related technology (COBIT) 246
 control unit 161–163
 Cooperation Laboratory 62–63
 Corporate Sustainability Due Diligence
 Directive (CSDDD) 202
 Corporate Sustainability Reporting Directive
 (CSRD) 202
 CRA. *see* Cyber Resilience Act (CRA)
 CRM. *see* customer relationship
 management (CRM)
 CSDDD. *see* Corporate Sustainability Due
 Diligence Directive (CSDDD)
 CSRD. *see* Corporate Sustainability
 Reporting Directive (CSRD)
 customer relationship management
 (CRM) 251
 Cyber Resilience Act (CRA) 89
 cybersecurity 53–54
 challenges 89–90
 IT services 245–246
 mitigation strategies 244, 248–250
 organizational measures 252–255, 253
 remote lab architectures 250–252, 252
 risks 244, 246–247
 technical measures 255–259
 threats 244, 247–248
 cytostatics 1, 4

d

DAQ. *see* data acquisition (DAQ)
 data acquisition (DAQ) 250
 databases 25, 37, 66, 96, 128, 131, 217, 246
 automation 132
 chemical 59
 laboratory 57
 NoSQL 245
 relational 245
 data blocks (DBs) 166
 data competences 105–106
 data curation 106
 data format standards 77

- data integrity 37, 87
 - data link layer 78
 - data literacy 105
 - data models 99
 - data privacy 31–32
 - data processing 103, 104, 105, 109–111, 110, 114–118
 - centroiding 103, 104
 - challenges 115–116
 - data competences 105–106
 - data format/structure 102
 - data quality 102
 - data science, advances in 118
 - open-source processing software 106–108, 116–117
 - StreamFind 108–109, 109
 - transparency 117–118
 - vendor software 106–108, 116–117
 - data-processing workflow software 102, 103
 - documentation 108
 - reproducibility 107
 - data protection 20
 - data quality 21, 95, 96, 102, 117, 123, 176
 - data science 23, 67
 - advances in 118
 - skills and competencies 71
 - transparency 117
 - data security 21–22, 257–258
 - data-specific workflows 106
 - data standards, 95–97. *see also specific data standards*
 - automation 111
 - basics of 97–99, 97, 98
 - future perspective 113–114
 - human-readable 97–98
 - non-human-readable 97
 - open data standards, use cases for 99–101
 - open-source vs. proprietary software 112
 - software to read, write, and process open data standards 101–102
 - timeline of vendor and open data standards 96
 - data strategy 67–68
 - DBs. *see* data blocks (DBs)
 - DCS. *see* distributed control systems (DCS)
 - DDoS. *see* distributed denial of service (DDoS)
 - deep learning 223–225
 - degrees of freedom (DOF) 150, 177
 - delta robots 149
 - Denso 150
 - device communication 77–78
 - Dictionary References 88
 - digital documentation 20, 25–26
 - digital format 36–38, 41, 51, 53
 - digital images 35
 - digital instrument logs 22
 - implementation 22–24, 23
 - templates 22–23
 - digitalization 5, 35, 41–42, 63, 81, 91–92, 140–141, 202, 220–230, 228
 - digital natives 64–65
 - Digital Product Passport (DPP) 224
 - digital solution 36
 - data integrity 37
 - manual documentation 36–37
 - reproducibility 37–38
 - stringent standards 36
 - digital SOP 130–131, 133
 - digital transformation 35–72, 139–140
 - academic research, shortcomings of 70–72
 - digital twin 53, 135, 140–141
 - digitization 8, 22, 35, 221–223, 243, 259
 - digital transformation vs. 41–42
 - digitized laboratory environment 42–44, 79
 - distributed control systems (DCS) 251
 - distributed denial of service (DDoS) 247
 - DOF. *see* degrees of freedom (DOF)
 - do-it-yourself (DIY) low-cost approach 125–126
 - DPP. *see* Digital Product Passport (DPP)
 - drift-tube IMS system 187–188
 - driver development 58–59
 - DryLab 227
 - dull, dirty, and dangerous (3D tasks) 146
- e**
- education 233
 - EEA. *see* European Economic Area (EEA)
 - effect-based analysis 3–5, 148
 - EGNATON CERT 202, 210, 217–218
 - EGNATON e.V. 201
 - EIF. *see* Environmental Impact Factor (EIF)
 - electronic laboratory notebook (ELN) 6, 17–34, 42, 56, 66, 96, 220, 251

electrospray ionization (ESI) 183, **184**
 ELN. *see* electronic laboratory notebook (ELN)
 ELNFinder 30–31
 end effectors 151–163
 end of arm tooling (EOAT) 151–152, 177
 endpoint detection and response (EDR)
 tools 258
 end-to-end (E2E) process 68–69
 Energy Star® programs 202
 enterprise resource planning (ERP) 251
 Environmental Impact Factor (EIF) 217
 EOAT. *see* end of arm tooling (EOAT)
 ERP. *see* enterprise resource planning (ERP)
 ESI. *see* electrospray ionization (ESI)
 European Economic Area (EEA) 31
 explorative laboratory 46
 Extensible Markup Language (XML) 98
 external instruments 158–160

f

FBD. *see* Function Block Diagram (FBD)
 FDM. *see* fused deposition modeling (FDM)
 field programmable gate array (FPGA) 251
 Findable, Accessible, Interoperable, and
 Reusable (FAIR) Data Principles 8,
 66, 72, 88
 FINDUS 160
 finger grippers 153
 FLD. *see* fluorescence detectors (FLD)
 flexible automation 145–147, 168–177
 components 148–163
 FutureLab.NRW 147–148
 installation 163–164
 practical experiences 164–167
 safety considerations 167
 small automation lexicon 177–178
 fluorescence detectors (FLD) 185
 force-limiting cobots 149
 force sensors 155
 format validation 99
 FPGA. *see* field programmable gate array
 (FPGA)
 functional integration 60
 hardware layer 60–61
 software layer 61
 Function Block Diagram (FBD) 162, 178
 fused deposition modeling (FDM) 192

fused silica 189
 FutureLab.North-Rhine-Westphalia
 (FutureLab.NRW)
 effect-based analysis 3–4, 6
 FAIR data principles 8
 flexible laboratory automation 147–148
 instrumental analysis 1–3, 6
 software platform 6–8

g

GAC. *see* Green Analytical Chemistry (GAC)
 gas chromatography-mass spectrometry
 (GC-MS) 98, 101
 gateway 53–54
 gateway connector 54–55
 GC-MS. *see* gas chromatography-mass
 spectrometry (GC-MS)
 generic data processing workflows 106
 genome-wide association studies
 (GWAS) 230
 German National Research Data
 Infrastructure (NFDI) 71
 Google 229
 Google IoT Cloud 55
 graphical user interface (GUI) 47, 60
 grassroots initiatives, importance of 233
 Green Algorithm 4 HPC Calculator 230
 Green Algorithm Calculator 230
 Green Analytical Chemistry (GAC) 202,
 219
 green lab 208
 Green Labs Austria 201
 Green Labs NL 201
 Green Sample Preparation (GSP) 219, 219
 greenwashing 233–234
 Green Your Lab 201
 grippers 152–154
 gripping force 152
 gripping width 152
 GSP. *see* Green Sample Preparation (GSP)
 GUI. *see* graphical user interface (GUI)
 GWAS. *see* genome-wide association studies
 (GWAS)

h

hand-guiding cobots 149
 hardware layer 60–61
 Heidelberg Accord 214

high-performance liquid chromatography (HPLC) 181–182
 HMI. *see* human-machine interface (HMI)
 HPLC. *see* high-performance liquid chromatography (HPLC)
 HTTP/2 80, 82
 human-machine interface (HMI) 166, 178
 “human plug and play” connectivity 85–86, 87
 human-readable data standards 97–98

i

IBM Watson IoT 55
 ICT. *see* information and communication technology (ICT)
 IDS. *see* intrusion detection systems (IDS)
 IEC. *see* International Electrotechnical Commission (IEC)
 IFMA. *see* International Facility Management Association (IFMA)
 IIoT. *see* Industrial Internet of Things (IIoT)
 IL. *see* Instruction List (IL)
 ILs. *see* ionic liquids (ILs)
 IMS. *see* ion mobility spectrometry (IMS)
 Industrial Internet of Things (IIoT) 223
 industrial labs 232–233
 industrial robot 148–149
 information and communication technology (ICT) 228
 Instruction List (IL) 162, 178
 interactive plots 109–110, 110
 International Electrotechnical Commission (IEC) 79
 International Facility Management Association (IFMA) 205
 Internet of Things (IoT) 42–44, 58, 59, 43, 223–225
 interoperability challenges of vendor formats 96
 inter-process software integration 59
 intrusion detection systems (IDS) 257
 ionic liquids (ILs) 226
 ion mobility spectrometry (IMS) 187
 IoT. *see* Internet of Things (IoT)
 ITIL. *see* IT infrastructure library (ITIL)
 IT infrastructure library (ITIL) 246
 IT services 245–246

j

JavaScript Object Notation (JSON) 98
 JSON. *see* JavaScript Object Notation (JSON)

k

KUKA 150

l

labeling workflow 127–128
 implementation 128–129
 LabIMotion 26
 lab/laboratory automation
 automation, impact of 171–172
 in chemical industry 168
 history of 145–147
 industrial automation 169–170
 mobile robots 172–173
 no-code and low-code programming 170–171
 open-source 83
 standards 83–84
 trends and challenges 83–84
 Lablicate GmbH 112
 lab-on-a-chip (LoC) systems 5, 182, 188–192
 Laboperator
 LES 121, 130
 temperature dashboard 126
 workflow 137
 Laboratory Analytical Device
 Standardization Open Platform
 Communication Unified Architecture (LADS OPC UA) 40–41, 64, 66, 69, 77, 84–91, 140
 challenges 88–89
 communication paradigms 79–81
 companion specifications 86
 cybersecurity challenges 89–90
 development 79
 future perspective 88–89
 human vs. machine plug and play 87
 ontologies 87–88
 origins 79
 SiLA 2 vs. 82
 standardization 85, 90–91
 taxonomies 87–88

- laboratory digitization 35
 - laboratory execution system (LES) 47, 56, 59–60, 66, 251
 - Laboratory Information Management System (LIMS) 42, 56–57, 66, 168, 251
 - laboratory logistics 159
 - laboratory robots 151
 - labos1point5 201, 217
 - lab transformation 4–5. *see also* digital transformation
 - digitalization 5
 - LABVOLUTION 139
 - Ladder Diagram (LD) 162, 178
 - LADS OPC UA. *see* Laboratory Analytical Device Standardization Open Platform Communication Unified Architecture (LADS OPC UA)
 - LC & GC Simulator 227
 - LC-MS. *see* liquid chromatography-mass spectrometry (LC-MS)
 - LC-MS/MS 1–3
 - LD. *see* Ladder Diagram (LD)
 - LEAF 201, 215–216
 - legacy device 39, 39–40
 - legacy equipment 39
 - LES. *see* laboratory execution system (LES)
 - light-emitting diode (LED)
 - technology 185–187
 - LIMS. *see* Laboratory Information Management System (LIMS)
 - linear robots 149
 - liquid chromatography 182–185
 - capillary chromatography 185, 186
 - chromatographic methods 182–183
 - liquid chromatography-mass spectrometry (LC-MS) 101
 - liquid-handling devices 158
 - load capacity 150
 - long-term archiving 21
- m**
- mAbs. *see* monoclonal antibodies (mAbs)
 - machine learning (ML) 141–142, 223–225
 - machine plug and play 86–87
 - magnetic grippers 154
 - manual tool changer 156
 - mapping process 48
 - market data 147
 - mass spectrometers (MS) 96, 183
 - Max Planck Sustainability Network (MPSN) 201
 - Meta 229
 - metadata 19
 - methodical approach, digital
 - transformation 44, 45
 - driver development 58–59
 - functional integration 60–61
 - gateway connector 54–55
 - integrating inter-process software 59
 - IoT server 59
 - middleware selection 55–57
 - network protocols selection 57–58
 - objective 46–48
 - stakeholder acquisition 44–46
 - workflow abstraction 51–54
 - workflow analysis 48–49, **50**
 - workflow implementation 59–60
 - MFA. *see* multi-factor authentication (MFA)
 - micropollutants 3
 - Microsoft 229
 - Microsoft Azure IoT 55
 - middleware 43, 55
 - commercial IoT platform 55–56
 - software ecosystem 56–57
 - miniaturization 182–185, 194
 - current problems 195–196
 - FutureLab.NRW 5
 - lab-on-a-chip systems 188–192
 - new possibilities with miniaturized detectors 185–188
 - technical and scientific challenges 195
 - 3D-printed microfluidic devices, potential use cases of 192–194
 - miniaturized detectors 185–187
 - field analysis 187–188, 188
 - miniaturized sensor platform 193, 194
 - miniaturized total analysis system (μ TAS) 189
 - Minolta 157–158
 - ML. *see* machine learning (ML)
 - MLP. *see* multilayer perceptron (MLP)
 - mobile robots 10–11, 151, 172–173
 - monitoring systems 160–161
 - monoclonal antibodies (mAbs) 4
 - MPSN. *see* Max Planck Sustainability Network (MPSN)

MQTT 125
 MS. *see* mass spectrometers (MS)
 multidimensional analytical data 101
 multi-factor authentication (MFA) 249
 multilayer perceptron (MLP) 141
 My Green Lab® 201
 My Green Lab's ACT® label 202

n

NACH-LABS 201
 Nano-FLD 186, 187
 network layer 78
 network protocols 57–58, 58
 network security 256–257
 network segmentation 256
 NFDI. *see* German National Research Data Infrastructure (NFDI)
 NIH. *see* US National Institutes of Health (NIH)
 non-human-readable data standards 97
 Non-Target Screening (NTS) 106
 NTS. *see* Non-Target Screening (NTS)

o

off-the-shelf software 124
 OneNote 30
 ontologies 19, 33, 88, 99
 OPC Foundation 79, 89–90
 OPC UA Security Working Group 89
 open-access tool 234
 OpenChrom 102, 111, 114
 open data standards 83, 96–97, 98, 99, 101–102
 basic parameters 99–100
 Openlabs CDS software 136
 Open-Source Lab 160
 open-source processing software 106–107, 112, 116–117
 open system interconnection (OSI)
 model 57
 application layer 78
 data link layer 78
 network layer 78
 physical layer 78
 presentation layer 78
 session layer 78
 transport layer 78

orchestration 121, 134–135, 134
 organizational measures of cybersecurity
 252, 253, 254–255
 education and training 253
 policies and governance 253–254
 risk assessment and management 254

p

PAC. *see* programmable automation controller (PAC)
 paper-based documentation 127
 parallel grippers 152
 payload 178
 PCA. *see* principal component analysis (PCA)
 PDMS. *see* polydimethylsiloxane (PDMS)
 PEEK. *see* polyetheretherketone (PEEK)
 Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) 205
 PFAS. *see* Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS)
 physical functional integration 60–61
 physical layer 78
 PLC. *see* programmable logic controllers (PLC)
 plug-and-play connectivity 81–82, 85–86, 87, 93
 point vacuum cups 153
 polydimethylsiloxane (PDMS) 190
 polyetheretherketone (PEEK) 187, 191, 192
 polypropylene (PP) 191, 192
 power-limiting cobots 149
 Power Usage Efficiency (PUE) 230
 PP. *see* polypropylene (PP)
 PreSens sensors 137, 138
 presentation layer 78
 principal component analysis (PCA) 226
 proactive controls or strategies 249
 process control
 commands 52–53
 variables 53
 Process Field Bus (Profibus) 178
 Profibus. *see* Process Field Bus (Profibus)
 Profinet 178
 programmable automation controller (PAC) 251

- programmable logic controllers (PLC) 148, 161–162, 178, 250
- proprietary software 116, 117
- Protobuf. *see* Protocol Buffers (Protobuf)
- Protocol Buffers (Protobuf) 80
- proximity sensors 155
- PUE. *see* Power Usage Efficiency (PUE)
- q**
- quantitative structure-activity relationship (QSAR) modeling 226
- quantitative structure-property relationship (QPSR) modeling 225
- quartz 189
- r**
- ransomware attacks 243
- Raspberry Pi 54–55
- RawFileReader 101
- RBAC. *see* role-based access control (RBAC)
- reactive controls 249
- reactive strategies 249
- remote controlled laboratory 47
- remote lab architectures, cybersecurity threats in 250–252, 252
- remote laboratory security audits 259
- Representational State Transfer Application Programming Interface (REST APIs) 80
- reproduction crisis 17
- REST APIs. *see* Representational State Transfer Application Programming Interface (REST APIs)
- RoboDK 157
- robotic hand grippers 153
- robotic laboratory automation 146
- Robotmaster 157
- Robot Operating System (ROS) 158, 178
- Roche 91–92
- role-based access control (RBAC) 256
- ROS. *see* Robot Operating System (ROS)
- RS232 interface 53
- s**
- safety monitored stop cobots 149
- sample preparation devices 158
- SBC. *see* single-board computer (SBC)
- SCARA. *see* Selective Compliance Assembly Robot Arm (SCARA)
- Scripps Institution of Oceanography (SIO) 210
- SCRM. *see* supply chain risk management (SCRM)
- security incident and event management (SIEM) solutions 258
- Selective Compliance Assembly Robot Arm (SCARA) 149
- SELs. *see* Sustainable European Lab Network (SELs)
- semantics 84, 98–99
- semi-automatic laboratory 47
- semi-stationary robots 151
- sensors 154–155
- Sequential Function Chart (SFC) 162, 165, 166, 178
- service level agreements (SLAs) 246
- session layer 78
- SFC. *see* Sequential Function Chart (SFC)
- Siemens S7–1500 series 162
- SiLA. *see* Standardization in Lab Automation (SiLA)
- single-board computer (SBC) 160
- single sign-on (SSO) 256
- SIO. *see* Scripps Institution of Oceanography (SIO)
- SLAs. *see* service level agreements (SLAs)
- small automation lexicon 177–178
- smart digital workflows 121–122
 - atline analysis, automation and orchestration of 133–138
 - labeling workflow 127–129
 - stock solution workflow 129–133
 - temperature monitoring 122–127
- SmartGlasses 141
- SmartLab
 - academic research 142
 - artificial intelligence 141–142
 - digital transformation 139–140
 - interdisciplinary environment 140–141
 - machine learning 141–142
 - workflows 109–110
- software layer 61
- software security 258
- solvent selection 226
- SOP. *see* standard operating procedure (SOP)
- speed and separation cobots 149

SSO. *see* single sign-on (SSO)
 ST. *see* Structured Text (ST)
 stakeholders 46
 business cases 70
 chemical industry, digital transformation 70
 financial support 70
 guidelines 70
 technologies, enabling 70
 vision 70
 Standardization in Lab Automation (SiLA) 77, 81–84
 communication paradigms 79–81
 development 79
 open-source, role of 83
 origins 79
 plug-and-play connectivity 81–82
 reasons, for relaunch 81–82
 SiLA 2, 40–41, 82, 140
 standardization 82–84
 status quo of 82
 standard operating procedure (SOP) 121
 stationary robots 151
 stereolithography 191
 stock solution workflow 129
 device integration and communication 131–132
 digital SOP 130–131, 133
 efficiency gains 132
 objectives 130
 process comparison 132
 StreamFind
 JSON workflow 109
 with NTS workflow 109
 Structured Text (ST) 162, 178
 suction pads 153
 supervisory control and data acquisition (SCADA) system 250–251
 supply chain management (SCM) systems 251
 supply chain risk management (SCRM) 254
 SUSSOL. *see* Sustainable Solvents Selection and Substitution Software (SUSSOL)
 Sustainable European Lab Network (SEs) 201

sustainable laboratory 201–204, 211–230, 232–234
 education and importance of grassroots initiatives 233
 energy consumption of typical instruments **206**
 green laboratory certification schemes 215
 greenwashing 233–234
 Heidelberg Accord 214–215
 holistic approach to science and sustainability 204–205
 labos1point5 201, 217
 LEAF 216
 open-access tool 234
 science impacts 205–210, 209
 sustainability as pivotal pillar of future lab 232–234
 sustainability in science 203–204
 sustainability trends in lab 203–220
 sustainable initiatives and grassroots groups **212–213**
 Sustainable Solvents Selection and Substitution Software (SUSSOL) 225
 syntax layer 78

t

TCP. *see* tool center point (TCP)
 technical measures of cybersecurity 255, 255
 access control and authentication 255–256
 audits 259
 data security 257–258
 monitoring and logging 258–259
 network security 256–257
 software security 258
 temperature monitoring 122, 123, 123
 accurate temperature control 122
 alarms 126–127, 127
 comprehensive temperature monitoring 122
 do-it-yourself low-cost approach 125–126
 manual 122–123
 notifications 126–127
 off-the-shelf software 124

temperature monitoring (*Cont.*)
 online 19
 paper-based 123
 reliable and robust 122
 Thermo Fisher Scientific Compound Discoverer™ 101
 third-party software platforms 157
 3D-printed microfluidic devices
 potential use cases of 192–194
 sensor platforms for accelerating bioprocess development 193–194
 time-of-flight (TOF) detection 103
 TLS. *see* transport layer security (TLS)
 tool center point (TCP) 164, 178
 tool changer 155–156
 torque sensors 155
 total laboratory automation (TLA)
 approach 146
 Touchbeamers 142
 transport layer 78
 transport layer security (TLS) 257
 triggers 48, 49, 107
 2LabsToGo 160

u

UA Binary 80
 UA XML 80
 UCSD. *see* University of California, San Diego (UCSD)
 ultra-low temperature (ULT) freezers 217
 unified data format 114
 Universal Robots 150
 University of California, San Diego (UCSD) 210
 unstructured data 6, 56, 106, 245
 US National Institutes of Health (NIH) 18

v

vendor software 106–107, 116–117
 data processing, challenges
 with 115–116
 versioning 20–21
 virtual private networks (VPNs) 257
 vision sensors 154–155
 VPNs. *see* virtual private networks (VPNs)

w

weighing procedure analysis **50**
 Wellcome Trust 210
 workflow abstraction
 automation 52
 cybersecurity 53–54
 digitization of measured values 51–52, 51
 gateway 53–54
 gateway connector 54–55
 process control commands 52–53
 process control variables 53
 steps 51
 workflow analysis 48–49, **50**
 workflow functionality 121
 workflow implementation 59–60
 workflow management 159

x

XML. *see* Extensible Markup Language (XML)

y

Yaskawa 150
 Yet Another Markup Language (YAML)
 format 121

z

Zigbee 125